



NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

THESIS

**IMPROVING LEGACY AIRCRAFT SYSTEMS
THROUGH CONDITION-BASED MAINTENANCE:
AN H-60 CASE STUDY**

by

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September 2014

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REPORT DOCUMENTATION PAGE			<i>Form Approved OMB No. 0704-0188</i>	
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instruction, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188) Washington DC 20503.				
1. AGENCY USE ONLY (Leave blank)		2. REPORT DATE September 2014	3. REPORT TYPE AND DATES COVERED Master's Thesis	
4. TITLE AND SUBTITLE IMPROVING LEGACY AIRCRAFT SYSTEMS THROUGH CONDITION-BASED MAINTENANCE: AN H-60 CASE STUDY			5. FUNDING NUMBERS	
6. AUTHOR(S) Joshua A. Reeder				
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Postgraduate School Monterey, CA 93943-5000			8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING /MONITORING AGENCY NAME(S) AND ADDRESS(ES) N/A			10. SPONSORING/MONITORING AGENCY REPORT NUMBER	
11. SUPPLEMENTARY NOTES The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government. IRB Protocol number ____N/A____.				
12a. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release; distribution is unlimited			12b. DISTRIBUTION CODE	
13. ABSTRACT (maximum 200 words) <p>Condition-Based Maintenance (CBM) has been the focus of Department of Defense efforts to reduce the cost of maintaining weapons systems for nearly two decades. Through an investigation of the MH-60S helicopter, this paper uses a gap analysis framework to determine the value of increasing CBM usage.</p> <p>The Naval Aviation Maintenance Program (NAMP) has used scheduled inspections as the backbone of aviation maintenance since 1959. The most significant of these inspections is the phase cycle, which provides inspection of aircraft components based on flight hours. This study uses the MH-60S to conduct a capability gap analysis for CBM in naval aviation. Through the use of a JCIDS Capabilities Based Assessment, the capability gap between the CBM enabling IMD-HUMS and the NAMP phase cycle is determined. From this gap analysis, Earned Value Management (EVM) tools determine the value of closing the CBM capability gap between the phase maintenance and IMD-HUMS in terms of cost and safety. Finally, an alternative phase maintenance structure is proposed for MH-60S maintenance which leverages the CBM capabilities of the IMD-HUMS to reduce total lifecycle costs.</p>				
14. SUBJECT TERMS Naval Aviation, Condition-Based Maintenance (CBM), Gap Analysis, Naval Aviation Maintenance Program (NAMP), Value Engineering, Earned Value Management, MH-60S, Phase Maintenance			15. NUMBER OF PAGES 143	
			16. PRICE CODE	
17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified	20. LIMITATION OF ABSTRACT UU	

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CONDITION-BASED MAINTENANCE: AN H-60 CASE STUDY**

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Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN SYSTEMS ENGINEERING MANAGEMENT

from the

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ABSTRACT

Condition-Based Maintenance (CBM) has been the focus of Department of Defense efforts to reduce the cost of maintaining weapons systems for nearly two decades. Through an investigation of the MH-60S helicopter, this paper uses a gap analysis framework to determine the value of increasing CBM usage.

The Naval Aviation Maintenance Program (NAMP) has used scheduled inspections as the backbone of aviation maintenance since 1959. The most significant of these inspections is the phase cycle, which provides inspection of aircraft components based on flight hours. This study uses the MH-60S to conduct a capability gap analysis for CBM in naval aviation. Through the use of a JCIDS Capabilities Based Assessment, the capability gap between the CBM enabling IMD-HUMS and the NAMP phase cycle is determined. From this gap analysis, Earned Value Management (EVM) tools determine the value of closing the CBM capability gap between the phase maintenance and IMD-HUMS in terms of cost and safety. Finally, an alternative phase maintenance structure is proposed for MH-60S maintenance which leverages the CBM capabilities of the IMD-HUMS to reduce total lifecycle costs.

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LIST OF ACRONYMS AND ABBREVIATIONS

AE	Age Exploration
AE	Aviation Electrician's Mate
AO	Aviation Ordnance man
AT	Aviation Electronics Technician
ATABS	Automated Track and Balance Set
BIT	Built-In Test
BUNO	Bureau Number
CBA	Capabilities Based Assessment
CBM	Condition-Based Maintenance
CBM+	Condition-Based Maintenance Plus
CMC	Commandant of the Marine Corps
CNO	Chief of Naval Operations
COMFRC	Commander, Fleet Readiness Centers
COMNAVAIRFOR	Commander, Naval Air Forces
CONOPS	concept of operations
CVW	carrier air wing
D-Level	depot level
DOD	Department of Defense
DON	Department of the Navy
DTMU	Data Transfer Memory Unit
DTU	Data Transfer Unit
EVM	Earned Value Management
FCF	functional check flight
FRS	Fleet Replacement Squadron
GS	Ground Station
HAZREP	Aviation Hazard Report
HSC	Helicopter Sea Combat Squadron
HSCWP	Helicopter Sea Combat Wing, Pacific
HUMS	Health Management Usage System
I-Level	intermediate level

IMDS	Integrated Mechanical Diagnostic System
IVHMS	Integrated Vehicle Health Management System
IVHMU	Integrated Vehicle Health Management Unit
JCIDS	Joint Capabilities Integration and Development System
MAF	Maintenance Action Form
MDT	Maintenance Down Time
MFD	Multifunction Display
MMP	Monthly Maintenance Plan
MOP	measure of performance
MRC	Maintenance Requirement Card
MTBM	Mean Time Between Maintenance
NAE	Naval Aviation Enterprise
NALCOMIS	Naval Aviation Logistics Command Management Information System
NAMP	Naval Aviation Maintenance Program
NAVAIR	Naval Air Systems Command
OBS	on-board system
OEF	Operation Enduring Freedom
OIF	Operation Iraqi Freedom
O-Level	operational level
OOMA	Optimized Organizational Maintenance Activity
PCMCIA	Personal Computer Memory Card International Association
PMI	Planned Maintenance Interval
RCM	Reliability Centered Maintenance
SBM	Similarity Based Models
SE	support equipment
SHARP	Sierra/Hotel Advanced Readiness Program
T/M/S	Type/Model/Series
TD	technical directive
TM	Type Maintenance Code
VGA	Value Gap Analysis
VIB-100	<i>Vibration Analysis Manual (ATABS)</i>

VIB-200
WESS

Vibration Analysis Manual (IMDS)
Naval Safety Center Web Enabled Safety System

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EXECUTIVE SUMMARY

The cost of developing and maintaining weapons systems has become a central focus of managers within the Department of Defense (DOD) in recent years. Following the downsizing of the U.S. military after the Cold War and the Global War on Terror, all communities within the DOD have been forced to find ways to reduce the cost of doing business. The U.S. Navy has expressed a desire for nearly two decades to streamline the maintenance process for weapons systems through the use Condition-Based Maintenance (CBM) to reduce lifecycle costs. Within Naval Aviation, a series of tools, such as the Goodrich Integrated Mechanical Diagnostic-Health Usage Management System (IMD-HUMS), have been developed to enable greater CBM capability.

To date, this CBM capability has not been fully implemented, and aviation maintenance is still based upon inspection cycles. The continued reliance on this decades-old maintenance program and its use of inspections has created a substantial capability gap in relation to the desired CBM capability. This study applied a capability gap analysis to the current Naval Aviation Maintenance Program (NAMP) using the MH-60S helicopter as its focus. The focus of this study was on the phase inspection process, which serves as the backbone of the current NAMP. Through the use of a JCIDS Capabilities Based Assessment (CBA), the CBM capability gap was assessed and an alternative maintenance process using CBM in the MH-60S was proposed.

The results of the study show that Integrated Mechanical Diagnostic System (IMDS) is capable of supporting a more robust CBM capability using data currently collected from aircraft. IMDS was also found to provide no statistically significant capability in its current usage other than a slight reduction in functional check flight (FCF) flight hours. The alternative phase model attempted to evolve the current phase model through the introduction of CBM. The alternative case keeps phase inspections in place at the same intervals as the current process, but with a greatly reduced number of component inspections. The inspections removed from the phase process involve engine, rotor and drive train systems which are currently monitored by IMDS. The comparison

of the baseline and alternative models revealed a significant value to implementing greater CBM.

The primary goal of this study was to create a baseline of current maintenance performance in the MH-60S and use a capability gap analysis to create a CBM alternative. Using the work of Langford and Franck (2009) on the application of Value Engineering and Earned Value Management (EVM) to Gap Analysis, the value of closing the CBM gap within the MH-60S maintenance process was determined. The study used data collected from a sampling of aircraft from the Helicopter Sea Combat Wing Pacific (HSCWP) from July 2013 to August 2014.

Using measures of performance related to maintenance labor hours, flight hours, availability and flight safety, the baseline case was created for maintenance performance. A series of comparisons was made between aircraft both equipped with the CBM enabling IMDS system and aircraft without IMDS. These comparisons were used to determine the value of IMDS as currently used in the fleet. Following the construction of the baseline case, IMDS ground station data was used to determine the efficacy of IMDS to implement CBM capabilities. Using this information, an alternative phase inspection scheme was created that used CBM to replace phase inspections of IMDS monitored systems. This alternative phase was then compared to the baseline case to determine the value of closing the CBM capability gap using the work of Langford and Franck (2009). Finally, flight safety data was used to help determine the possible effects of decreased human inspection on aircraft mechanical failures.

The study assessed value based on the number of flight hours available per labor hour during phase inspections. This value increased from 0.35 flight hours per phase labor hour under the baseline model to an average of 1.07 flight hours per phase labor hour with the alternative phase model. Additionally, the reduction of post-phase vibration analysis through only need-based inspections of engine and drive train systems increased available flight hours by 3.24 percent. This increase was a direct result in the virtual elimination of post-phase FCFs due to changes in the phase inspection process.

Availability of aircraft due to phase inspection down time increased from an average of 69 percent to 93.7 percent. This increase was mostly due to the reduced labor requirement during phase and the virtual elimination of post-phase FCFs. Additionally, the study found that maintenance labor hours decreased by an average of 1,270 hours per phase cycle, or about 318 hours per phase inspection under the alternative model. Finally, the flight safety data revealed that in the period from 2009-2014, 60 percent of MH-60S aircraft incidents caused by mechanical failure were as a result of human error in maintenance. The study determined that there was no evidence with the flight safety data to support any finding that the alternative phase model would compromise safety in a meaningful way. Furthermore, safety would likely be improved by reducing the human element of maintenance, which was the primary cause in a majority of reported mechanical failures.

This study supports the Navy's desired implementation of CBM into aviation maintenance processes. A capability gap was identified within the current process, and a reasonable alternative to current maintenance processes was proposed. This alternative model provides a significant value to the Navy and should be explored in practice within the fleet.

LIST OF REFERENCES

Langford, Gary O. and Raymond Franck. 2009. *Gap Analysis: Application to Earned Value Analysis*. Monterey, CA: Naval Postgraduate School, Aug. 19

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ACKNOWLEDGMENTS

This thesis was developed over the course of 15 months, and I would like to thank several individuals who made the effort possible. Professor Gary Langford was my project advisor and was an invaluable resource throughout the entire project. His work past served as the basis for this thesis, and he provided guidance from the time before I conceived the idea for this thesis until completion. Without his assistance, this thesis would not have been possible.

I would like to thank Professor Richard Millar, my second reader, who provided a great deal of guidance through my writing and editing effort.

Many people helped me collect the data necessary to make this project a reality. I would like to thank Stephen Boyer, the HSC-3 Goodrich IMD-HUMS technical representative for using his time to teach me the IMDS system. His guidance gave me a great understanding of how to create a CBM system and was invaluable in creating this thesis. I would also like to thank the personnel of HSC-3, HSC-8 and HSC-21 for helping gain access to all of the data systems needed for this project and for your help in collecting all of my data.

Finally, I would like to thank my wife, Annie, for all of her love and support during my entire graduate school process. Thank you for reading all of my papers, listening to me talk about engineering, and helping me through the last two years.

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I. INTRODUCTION

A. BACKGROUND

Since the end of the Cold War, the United States Department of Defense (DOD) has undergone a significant shift in priorities. Through the two decades since the fall of the Soviet Empire, the DOD has undergone a massive shift in focus away from the global conflicts that dominated the last century. After the events of 9–11, the DOD focused on combating terrorism and smaller scale, regional conflicts, which require a much different force to achieve success. After more than a decade of warfare, the United States has become a war-weary nation, and there are major questions about the future composition of the military. As the recent limited engagements in Libya have shown, air power is likely to be the key component of U.S. strategy with a lessened focus on ground forces. With this possible seismic change as the backdrop, the DOD must find ways to continue to execute its missions with greatly reduced resources. This resource-constrained environment will put stress related to both budgets and manning on all of the services, especially the U.S. Navy. The Navy will likely be responsible for developing new weapons systems while maintaining an active presence around the world.

After more than a decade of war, the DOD faces significant changes to future manning and force structure. This point was outlined by Secretary of Defense Chuck Hagel when discussing the Obama Administration’s FY2015 DOD budget proposal (Simeone 2014). In February 2014, Secretary Hagel detailed a series of “difficult choices” that must be made for each of the services since the overall defense budget would shrink by more than \$75 billion by 2016, with larger cuts likely to follow (Simeone 2014). This budget reduction is at the forefront of every decision throughout the force and Naval Aviation was not exempt from the budgetary declines. As explained in *Defense News* in March of 2014, the proposed FY2015 Naval Aviation budget saw significant cuts for procurement and operations. According to the budget proposal, procurement budgets would decrease for the year by nearly \$5.1 billion and operations and maintenance funding by \$1.7 billion, or nearly 4 percent (Cavas 2014).

With the aging of its current fleet, the Navy must find a way to maximize the life of current systems at a reduced cost while developing new systems that will fight the next generation of wars. Over the last several years, the Navy has seen a significant reduction at all levels of the force due to processes such as sequestration and right-sizing. Many legacy systems still provide needed capabilities but require maintenance and logistics efforts which have become severely outdated. In this environment, commanders at every level, from the Pentagon down to the operational ships and squadrons, have been forced to rethink how resources are managed. This change in direction also begs an important question: How does the Navy find safe and effective ways to employ current systems at a reduced cost?

To answer this critical question, an investigation of current processes is necessary in order to determine the best use of current and future resources. However, a single study cannot analyze every process throughout the Navy, as it has a diverse set of sea, air, and land-based systems. Instead, this study was limited, with clearly defined boundaries and focused on specific processes that can assist individual commanders in improving their own organization. This study focused on the operational aviation squadron, which serves as the smallest autonomous unit within the naval aviation enterprise. Research was confined to helicopter squadrons and the maintenance processes involving the MH-60S helicopter. This study attempted to determine the suitability of maintenance processes to operate in current and future resource-restrained environments. To achieve this goal, an analysis of capabilities was performed, gaps in capabilities were identified, and possible solutions were explored in order to determine how to best employ the MH-60 in the immediate future. This study's results will remain valid for the time period where calendar-based maintenance serves as the primary method of maintaining naval aircraft. A shift in maintenance to a Condition-Based Maintenance (CBM) program would go beyond the scope of this investigation and make its conclusions obsolete.

B. SCOPING THE MAINTENANCE COST PROBLEM

In the face of impending budget cuts, it is important to find ways to reduce costs without degrading or eliminating the capabilities of current systems. To resolve this issue,

it is important to analyze the current operations and maintenance structure of naval aircraft. Currently, all naval aviation units adhere to a single maintenance structure known as the Naval Aviation Maintenance Program (NAMP), which standardizes corrective and preventive maintenance processes fleet-wide. This program is explored to determine where improvements can be made and what tools are available to implement these changes.

The NAMP, officially known as the OPNAVINST 4790.2 series, was introduced in 1959 and was the first attempt to standardize maintenance processes throughout naval aviation. The NAMP has undergone a series of revisions in the last five decades, with the most recent release occurring in May 2012 (Commander Naval Air Forces [COMNAVAIRFOR] 2012). Even though changes have been made to the program, the overall structure has remained essentially unchanged from the first version released over five decades ago. The NAMP divides all maintenance efforts into three levels, operational, intermediate and depot, and assigns specific tasks to each level as appropriate (COMNAVAIRFOR 2012).

The operational level (O-level) refers to the day-to-day maintenance efforts of the operational unit that typically serves as the reporting custodian for the aircraft. In simpler terms, the operational level refers to maintenance performed by the unit, most typically a squadron or air wing, which operates the aircraft. The intermediate and depot levels refer to higher levels of maintenance that focus on inspecting and repairing equipment that cannot be maintained at the operational level. Intermediate and depot levels are also responsible for conducting maintenance related to improving and extending the service life of aircraft and support equipment (COMNAVAIRFOR 2012). For the purposes of this paper, the focus is on the operational level, as this is where a majority of the maintenance actions are conducted and most of the manpower is concentrated.

The NAMP details seven maintenance functions generally performed at the O-level: inspections, servicing, handling, on-equipment preventive and corrective maintenance, incorporation of technical directives, record keeping and Reliability Centered Maintenance (RCM) implementation (COMNAVAIRFOR 2012). One important note is the interaction of RCM and Condition-Based Maintenance (CBM).

CBM is discussed in length in this study and is the primary enabler of the RCM concept discussed in the NAMP. For simplicity sake, CBM shall be used throughout this study to refer to all principle related to both CBM and RCM.

Regardless of the type of maintenance, most O-level preventive maintenance functions are based on time cycles or the number of flight hours flown. Preventive maintenance at the O-level is centered on individual aircraft, so each airframe has its own set of requirements for inspections and maintenance actions. Some actions are scheduled based on the amount of time since the previous inspection and others on the number of hours flown or type of flight that was conducted. These inspections and the actions related to their completion form the backbone of O-level maintenance. Corrective maintenance actions are driven greatly by the results of these preventive maintenance inspections and the operational usage of aircraft components. The NAMP and its requirements will be explored in greater depth in following sections.

Having established the current state of naval aviation and its short and long-term need to reduce costs, this paper focuses on the ways that maintenance processes can be improved to save both resources and labor hours. The goal of this research is to find an effective measure of the usefulness of current processes and identify areas in which these processes can be improved using a systems engineering framework. To accomplish this goal, a capability gap analysis was conducted to determine, as Langford et al. (2007) noted, “the degree to which a current system satisfies a set of requirements.” In Chapters II-IV, the current state of aviation maintenance is detailed, the use of condition-based maintenance is described, and gap analysis is defined and conducted for the MH-60S.

The current NAMP, however, does not meet all of the performance goals outlined above. As is discussed in Chapter II, the current NAMP does meet the needs of the aviation force in terms of providing required warfighting capabilities. However, the NAMP does not meet the goals laid out in the *Naval Aviation Vision 2020* or DOD and OPNAV directives with respect to condition-based maintenance. These issues are explored in depth in Chapter III, as the failure of the NAMP in its current form to meet CBM goals is a major driver of this research.

This study attempts to answer the following four questions directly related to the continued safe and effective operation of naval aircraft:

1. How can naval aviation commanders improve the aircraft maintenance process at the organizational level in order to meet increasing operational requirements in a time of decreasing budgets?
2. What tools are available that can reduce the manpower and equipment requirements for operational squadrons, how effective are these tools, and are they being used to the greatest extent possible?
3. To what extent is there a gap between current capabilities and the requirement to meet the Navy's stated goal of maximizing the use of CBM at the organizational level?
4. Are there any possible solutions that may have been overlooked that could be more effective than the maintenance processes currently in use or development?

Through answering these questions, a capability gap analysis framework is developed and applied across Naval Aviation to meet the needs of both the DOD and public stakeholders.

In order to answer these questions, Chapter II explores the NAMP in-depth, which an understanding of its components and determine areas where cost-effective changes can be implemented. In Chapter III, an investigation of relevant literature is conducted, a theoretical gap analysis framework is explored, and CBM tools and processes are discussed. Chapter IV presents the capability gap analysis based on the Joint Capabilities Integration and Development System (JCIDS) Capabilities Based Assessment (CBA) and the relevant measures of performance and metrics. This capability gap analysis explores the research questions set forth above and constructs a systematic method for creating a viable alternative to the current NAMP process. Relevant data is presented, and the boundaries and scope of the analysis are clearly outlined and detailed. From this data, comparisons are made between both processes and aircraft, and the results of the analysis are presented in Chapter V. Finally, the formal conclusions of the study and possible extensions to future research are presented in Chapter VI.

C. APPROACH, METHOD, AND SCOPE

Since the research goals have been established, the next important step is to create a research approach that applies logical, systematic methods to the subject and construct a clear scope for the investigation. The first steps are to provide the primary approach for the research, determine the affected stakeholders, and provide the perspective necessary to make the research questions relevant to the stakeholders needs. Once this research approach has been established, the methods and processes can be detailed and the scope of the investigation can be presented.

The approach to this research is formulated from the perspective of the users of the MH-60S helicopter. The users constitute the most important set of stakeholders, since they are the ones most responsible for the daily operation and maintenance of the aircraft. The users are also the primary stakeholders responsible for the implementation of budget decisions and will be responsible for installing new processes. That is to say, since the users conduct most of the daily maintenance and all aircraft operations, they will be the stakeholders most affected by changes to the process that governs these areas. The users group, however, should not be taken to mean simply the pilots and aircrew that operate aircraft in flight. Instead, the users will be defined as the entire operational level squadron, including maintenance and support personnel that ensure proper aircraft operations. Since all members of an operational level squadron primarily focus on aircraft operations, even those acting in an administrative role, it is necessary to consider the entire squadron as users for this research. Therefore, this paper will frame decisions from the perspective of the user class. The research attempts to determine the value that users derive from processes and how this value might be improved through process changes.

With the most important stakeholders identified, the next stage in determining the best research approach is to establish the value added by this analysis. The principal goal is obviously to maximize the benefit to stakeholders given the set of constraints that exist. To accomplish this goal, the following must be established:

- How are benefits defined?
- What are the constraints?

- How will benefits and constraints be quantified and measured?

To answer these questions, a capability gap analysis framework was established to determine the value of process changes. The basis for this gap analysis has been derived from both the JCIDS Capabilities Based Assessment and the work of Langford and Franck (2009). Langford and Franck provide a method for determining the earned value of systems engineering, and the necessary value and worth equations will be derived and explained in more detail in Chapter III.

Benefits and constraints are closely related, as both are denominated in the same terms. For instance, the constraints from the stakeholder's perspective are the number of maintenance labor hours available and the budget for personnel and materials necessary for operations. Constraints are related to the operational commitments of individual squadrons, along with the equipment and physical space available to conduct maintenance and flight operations. Benefits are therefore measured in terms of the maximum use of constrained resources. This, in turn, is applied to the capability gap analysis. Through gap analysis, alternatives are created, the value of alternatives is determined, and areas where further engineering is required to achieve the necessary benefits are revealed. As with the research approach, the benefits and constraints of the stakeholders are explored in more depth in Chapters III-V.

Having established the desired research methods, it is also necessary to explain why these methods have any importance to the stakeholders, as well as the reasons for limiting the investigation to a single set of stakeholders. The choice of capability gap analysis is important due to its lengthy history of use within the DOD on acquisitions projects, which consequently provides a stable comparison to other studies. Gap analysis is directly related to the principles outlined in the JCIDS manual (CJCSI 3170.01H) and the *Defense Acquisition Guidebook* (DOD 5000 Series) (Langford and Franck 2009). By using this well-developed and understood framework as the basis for this analysis, the results and conclusions can be presented in a format that stakeholders throughout DOD can easily understand. Furthermore, resources are measured and denominated using the same metrics as the current NAMP processes, so a direct comparison of alternatives can be made and clear results determined. These comparisons will provide a greater

understanding of the results and conclusions throughout the naval aviation community, even to those with limited systems engineering experience.

The final area that must be determined is the scope of the analysis, meaning what are the particular activities within the boundaries of the investigation? Although the users are not the only stakeholders that will be affected by changes to the aviation maintenance process, their activities define the scope of this investigation. A narrow scope is necessary because an investigation of the entire aviation maintenance process would be expected to be extremely dense and offer comparisons that might be quite difficult to understand.

For instance, the Navy operates jet, rotary and maritime aircraft, which have very different maintenance requirements and are therefore difficult to compare directly. At the highest level of abstraction, such comparisons as “to maintain” are confounded by the lower-level details. Since each type of aircraft has diverse and different components and structures, the usage of maintenance labor hours should be expected to vary greatly across the different airframes. Therefore, a single airframe must be selected as the focus for the study. In this case, helicopters will be studied, specifically the MH-60S Knighthawk. The MH-60S provides an excellent basis for the study of maintenance processes, as there are currently multiple variants in service that employ different aircraft systems using the same NAMP processes. For this reason, data collected can easily be divided based on installed systems, which simplifies the comparisons that are made.

As stated earlier, this study will also be focusing on maintenance at the operational level. The operational level is the best place to investigate the maintenance process since it contains most of the maintenance manpower usage and all flight operations. Additionally, the operational level has been targeted by the Navy for the implementation of NAMP alternatives, such as the use of CBM. CBM is a primary focus of this study, since it serves as the preferred replacement for many processes in the NAMP (4790.16A 2007). Further, CBM has been the driver of multiple new systems built to ensure its capability, such as the Integrated Mechanical Diagnostics System (IMDS) in the MH-60S. Therefore, CBM is explored in great depth and serves as the primary alternative to the current maintenance process in this study’s comparisons.

Finally, the study will restrict its focus to the utilization of manpower and aircraft within the seven O-level maintenance areas established in Chapter 3 of the current NAMP (2012). This focus on the O-level allows for a comparison of process utility both within and between squadrons, with the primary focus being tasks related to phase inspections. The other areas listed still have significance, but inspections and preventive and corrective maintenance provide the best means of comparing legacy maintenance with CBM alternatives.

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II. NAVAL AVIATION MAINTENANCE PROGRAM (NAMP)

A. NAMP OVERVIEW

The history of naval aviation is littered with stories of both bravery and despair, as men and women have fought and died in service through the air. After more than a century of naval aviation, there are still great risks posed to aviators on a daily basis. However, over the course of the last century, there has been a quantum leap in the safety and reliability of the naval aviation enterprise. The hallmark of this great advance in flight safety is the standardization of processes related to both flying and maintaining aircraft. Following the Second World War, the U.S. Navy made a concerted effort to reduce the number of aircraft mishaps, especially those causing injury, death or destruction of aircraft. In order to accomplish this goal, a series of changes was implemented to the entire naval flight process, which focused on standardization of processes for aircrew, maintenance and administrative personnel. For the purposes of this research, the focus will be fixed on the effectiveness of the maintenance processes. Therefore, a detailed exploration of the current NAMP must be carried out to lay the groundwork for examination of its efficacy and vulnerabilities in the modern budget environment.

The NAMP contains an exhaustive description of all aviation maintenance processes and procedures, outlines the composition of maintenance programs, and delineates the responsibilities of each level of aviation maintenance. In essence, the NAMP seeks to govern the efforts of everyone involved with aircraft maintenance and guarantee that commonality is maintained across all platforms. This commonality helps to ensure that processes are identical, regardless of the squadron, wing, or depot performing the maintenance, and that procedures are applied identically regardless of the platform being maintained. The NAMP has created a level of standardization that allows maintenance personnel with specific expertise to work on any related system, regardless of platform. For example, an individual that specializes in engine maintenance may have spent the first 15 years of his or her career working on jets and jet engines. If a helicopter squadron requires an experienced engine mechanic, he or she can be reassigned to the

helicopter platform and the procedures for work are the same, even though the machine itself is different.

The NAMP has been very effective in helping lower the Class A mishap rate, meaning accidents leading to death, serious injury, or serious damage or destruction of aircraft. This rate has been reduced from 83.3 mishaps per 100,000 flight hours in 1945, to 51.2 in 1953, to 1.89 in 2003 (Naval Aviation Schools Command [NASC] 2005). However, the NAMP is not without its detractors, as the basic process has changed very little since its inception in 1959. The NAMP does not meet the Navy's current definition for best maintenance practices that is outlined in the OPNAV 4790.16A, CBM Instruction (2007). The NAMP itself even sets one of the operational level maintenance goals as the "age exploration (AE) of aircraft and equipment under RCM" (COMNAVAIRFOR 2013). The use of the operational level to validate RCM, and in turn CBM, suggests that CBM is the preferred by the Navy over the current process.

In an era of increasingly complex systems, the Navy's strict adherence to standard processes, regardless of their fitness, and flexibility of manning have created parallel issues for the efficacy of the NAMP. On one hand, standardization helps ensure interoperability between diverse platforms and makes the entire maintenance process more streamlined. On the other hand, this standardization has prevented system specific maintenance processes from being developed. Additionally, it has slowed the progress toward the use of integrated maintenance and monitoring equipment that could help reduce costs and labor. Furthermore, although maintainers can move between platforms under the NAMP, the complexity of modern systems makes this transition very time consuming. For the author of this study, personal experience as a maintenance branch division officer has shown that qualified and experienced individuals often take years to achieve a level of competence on a new platform equal to their previous platform.

To be able to answer the key research questions posed in Chapter I, a systematic examination of the current NAMP was conducted to form a baseline of maintenance processes that were used as a benchmark to measure possible alternatives. Since the NAMP is such an exhaustive resource, the focus of this research was narrowed in scope to the operational level of maintenance on the MH-60S platform. This scope does not

mean that other areas of the NAMP will be ignored, as the process is greatly integrated, It simply means that the majority of the effort will be focused at the organization level.

1. NAMP Organization

In Chapter I, there were four major research questions posed that seek to determine how future naval aircraft maintenance should be conducted. The first of these questions speaks to how operational commanders can improve processes in a time of increasing operational commitments and decreasing budgets. Finding a solution to this problem requires an understanding of the NAMP structure and contents.

The current maintenance program, outlined by the NAMP, is used fleet-wide by all aviation squadrons. The NAMP has provided a level of standardization and commonality between platforms and communities that has allowed successful flight operations for nearly six decades. However, as discussed in Chapter I, the military as a whole is undergoing a reorganization that will require significant budget cuts to all of the services over the next decade. With the uncertainty of future funding for many programs, the NAMP might not be the best available option in the future despite its past success in comparison to its predecessors. Standardization on the level demanded by the NAMP requires a significant funding effort to ensure compliance with its myriad of regulations. Therefore, finding ways to lessen the regulatory burdens posed by the NAMP could provide a great cost savings in the future.

With the impending shift in military funding, the discussion of the NAMP processes shall be focused on cost savings, as the program is quite expansive. In keeping with the scope of this study, the focus of this section is the operational level programs and processes used by MH-60S squadrons. Since the maintenance processes outlined in the NAMP include additional maintenance at both the depot and intermediate levels, changes at the operational level affect the frequency and category of these higher level maintenance functions. Since the operational level includes the majority of the maintenance effort and cost, it is appropriate to focus on this level along with a recommendation to extend this study to higher levels in the future. Therefore, the NAMP can be examined in the appropriate operational context for the purposes of this study.

The NAMP is divided into chapters which each contain a single, unified theme. There are currently a total of 17 individual chapters in the NAMP that detail the organizations, responsibilities, procedures, and structure of the entire aviation maintenance program from the CNO-level down to the operational level. For reference purposes, the NAMP can be found in its entirety on the NAVAIR website, <http://www.navair.navy.mil/logistics/4790>. The purpose of the NAMP is outlined in the following text from the COMNAVAIRFOR, which details the objectives of the program from the top level:

a. The objective of the NAMP is to achieve and continually improve aviation material readiness and safety standards established by the CNO/COMNAVAIRFOR, with coordination from the CMC, with optimum use of manpower, material, facilities, and funds. COMNAVAIRFOR aviation material readiness standards include:

(1) Repair of aeronautical equipment and material at that level of maintenance which ensures optimum economic use of resources.

(2) Protection of weapon systems from corrosive elements through the prosecution of an active corrosion control program.

(3) Application of a systematic planned maintenance program and the collection, analysis, and use of data in order to effectively improve material condition and safety.

b. The Naval Aviation Plan (secret) details logistics actions which will allow the maximum opportunity to achieve this objective.

c. The methodology for achieving the spirit and intent of the NAMP objective is labeled “performance improvement.” Performance improvement is an “all hands” effort which focuses on service and close support to customers. As a primary prerequisite, the mission must be clearly understood and communicated to everyone in the organization. It is essential that all personnel know their job, understand their contribution to mission accomplishment, and are sensitive to customer requirements. New or improved cost effective capabilities and processes must be continuously pursued. Mutually supporting teamwork, constant communication, and compatible measures are critical elements for success. Performance improvement must be targeted to accomplish the following broad goals:

(1) Increased readiness.

(2) Improved quality.

- (3) Improved deployability.
- (4) Improved sustainability.
- (5) Reduced costs.
- (6) Enhanced preparedness for mobilization, deployability, and contingency operations.
- (7) Enhanced supply availability.
- (8) Improved morale and retention.
- (9) Compliance with environmental laws, rules, and regulations.
(COMNAVAIRFOR 2013, 1-4)

This passage outlines the three system-level requirements of the NAMP: repair of equipment, control of corrosion, and systematic administrative oversight of the maintenance process. To meet these requirements, a maintenance program as a whole must achieve certain material readiness and safety standards as set forth in the Naval Aviation Plan. Since the Naval Aviation Plan is classified, the specific metrics for material readiness and safety that are considered successful are not conveyed in this passage.

On the other hand, any study of NAMP processes that propose alternatives, such as this one, must create measures of performance and metrics which apply to material readiness and safety. Performance measures and metrics are discussed broadly in Chapter IV, but this passage provides guidance for developing the metrics that are used to measure performance. This passage goes further in saying that NAMP processes, and by extension possible alternatives, must be focused on constant performance improvement. The definition and intent of performance improvement is conveyed through the nine goals listed above. Using these nine goals, measures of performance related to the MH-60S were created and applied to both current processes and possible alternative to form the basis for this study. Through the use of performance measures and metrics derived from the requirements and goals listed in this passage, the efficacy of maintenance processes and alternatives is determined.

2. Performance Improvement

Performance improvement in many ways serves as the focus of the NAMP, but simply stating a need for improvement provides no means to measure it. Helpfully, the NAMP does provide seven areas that are used as a basis for comparison of performance. The seven areas of performance are: productivity, effectiveness, efficiency, quality, innovation, quality of work life, and budgetability. (COMNAVAIRFOR 2013) Using these seven areas along with the top-level requirements presented in the previous section, metrics are focused on the areas considered most important by the NAMP. The combination of these seven areas and the nine performance improvement goals from the previous section on NAMP organization form the basis for this study's metrics and measures of performance. Therefore, these seven performance improvement areas along with the nine performance improvement goals are the NAMP's measures of effectiveness. These measures of effectiveness and performance along with associated metrics are discussed in Chapter IV and applied to the baseline and alternative maintenance models created in Chapter V. Having determined the stakeholders, requirements, goals, and metrics at the system level, the focus can now shift to the operational level and squadron specific processes.

3. Maintenance Levels

Chapter 3 of the NAMP provides the basic division of activities between the three levels of maintenance: depot, intermediate, and operational (COMNAVAIRFOR 2013). The following section provides a focused mission statement of the division of labor between the three levels of maintenance:

The NAMP, implemented through COMNAVAIRFOR, supports the CNO and the CMC readiness and safety objectives and provides for optimum use of manpower, facilities, material, and funds. The NAMP is founded upon the three-level maintenance concept and is the authority governing management of O-level, I-level, and D-level aviation maintenance. It provides the management tools required for efficient and economical use of personnel and material resources in performing maintenance. It also provides the basis for establishing standard organizations, procedures, and responsibilities for the accomplishment of all maintenance on naval aircraft, associated material, and equipment. (COMNAVAIRFOR 2013, 3-1)

This passage restates the goals provided at the system level and gives a clear statement of how these goals are translated to processes. To achieve this aim, the NAMP provides a description of the maintenance concept for each level and the actions that must be accomplished at that level. For the operational level, or O-level, the following overview is given:

O-level maintenance is performed by an operating unit on a day-to-day basis in support of its own operations. The O-level maintenance mission is to maintain assigned aircraft and aeronautical equipment in a full mission capable status while continually improving the local maintenance process. While O-level maintenance may be done by IMA/COMFRC activities, O-level maintenance is usually accomplished by maintenance personnel assigned to aircraft reporting custodians.

O-level maintenance functions generally can be grouped under the categories of:

- a. Inspections.
- b. Servicing.
- c. Handling.
- d. On-equipment corrective and preventive maintenance. (This includes on-equipment repair, removal, and replacement of defective components.)
- e. Incorporation of TDs, less SE, within prescribed limitations.
- f. Record keeping and reports preparation.
- g. AE of aircraft and equipment under RCM (COMNAVAIRFOR 2013, 3-1)

From this passage, the most important stakeholders are clearly the aircraft users at the operational level. For the purposes of this study, the term “users” will refer to the operational level aircrew and maintainers. Since ensuring material readiness and safety are the focus of the NAMP, O-level maintenance must ensure these two areas are met. Users, in the form of maintenance personnel, ensure the aircraft is in safe operating condition to meet operational tasking. Users, in the form of aircrew operators, also execute operational tasking and benefit directly from the safety provided by maintenance practices. For these reasons, users are the most important stakeholders at the O-level, and their concerns should always be the most important.

Using the NAMP guidance provided in the passage above, the seven functions of O-level maintenance are:

- To Inspect
- To Service
- To Handle
- To perform on-equipment corrective and preventive maintenance
- To incorporate TDs within prescribed limits
- To keep records and prepare reports
- To age explore aircraft and equipment under RCM

Since the users are the most important stakeholders at the O-level, these seven functions must be performed to meet the stakeholder's requirements. The stakeholder's requirements are not directly provided, but can be derived from the seven functions and the requirements of the NAMP at the system level. As discussed earlier in this chapter, the top-level NAMP functions are repair of equipment, control of corrosion, and systematic administrative oversight of the maintenance process. Translating these requirements to the operational level, the user's requirements are "maintain operational capability," "document maintenance actions," and "ensure safe operation of equipment."

The first requirement, "maintain operational capability," is met by performing the functions related to inspection, servicing, handling, maintenance, and TDs. These areas all detail how a squadron, the principle unit at the operational level, will maintain aircraft and support equipment in the condition necessary to meet operational tasking. The second requirement, "document maintenance," is clearly met by the function "to keep records and prepare reports." The final requirement "ensure safe operation of aircraft" is met by all of the seven functions, since performing these actions enables the safe operation of aircraft.

The primary short coming of the current maintenance process is shown by the final function "to age explore aircraft and equipment under RCM." As discussed in Chapter I, RCM is enabled by CBM, which is not currently practiced at the O-level.

The purpose of this requirement is to explore the efficacy of CBM at the O-level and collect data necessary to implement the Navy's desired CBM capability. Since CBM is not currently used as a maintenance method at the O-level, this function is not truly met and a capability gap exists at the O-level. This study seeks to determine the value of eliminating this CBM capability gap.

Reliability centered maintenance is the basis for CBM, which will be explored in depth throughout the rest of this thesis. In this case, RCM is presented as the only seriously considered solution to improve the maintenance process at the O-level. RCM might be the best alternative, but including a specific solution set within a requirement introduces an unnecessary bias to process of "performance improvement". A more appropriate term in this case would be to "conduct age exploration of aircraft and equipment under alternative processes" and then outline a series of possible alternatives that includes RCM. Even though RCM may prove to be the best alternative, the robust series of performance improvement goals described at the system level should be less specific to allow selection of the best performance solution.

B. NAMP PROCEDURES

Having established the stakeholders, requirements and functions at the O-level, the NAMP provides the procedures to be followed to satisfy the users' requirements. The primary maintenance procedures are provided in the NAMP Standard Operating Procedures, or NAMPSOPs. NAMPSOPs are detailed in Chapter 10 of the current NAMP edition, and are typically program-specific directives which detail the requirements for each maintenance program. For example, current NAMPSOPs outline programs such as quality assurance, discrepancy reporting, maintenance training and tool control. (COMNAVAIRFOR 2013) Each NAMPSOP serves as another level of decomposition in the aviation maintenance system, detailing the individual programs which exist at the operational level. From each NAMPSOP, more detailed descriptions of functions are determined by decomposing these top-level functions. These decompositions are equivalent to a detailed design effort in systems engineering. NAMPSOPs have a common architectural structure which is applied to all programs at

the operational level. This common architecture provides a structure for all existing maintenance programs, and serves as a template for the development of new programs which meet the “performance improvement” goals at the system-level.

1. Maintenance Department

In addition to the NAMPSOP, the architecture of the maintenance department is established with the NAMP. In this case, architecture refers to all of the operational processes that occur within a maintenance department to accomplish operational tasking. This architecture describes the chain of command within each maintenance department and the derivative work centers. The architecture standardizes the flow of tasks within the maintenance department, with each individual work center reporting to a maintenance control (COMNAVAIRFOR 2013). The work centers are sub-divided into the aircraft division and avionics/armament divisions (AV/ARM). Each division is then further divided into branches by aircraft system expertise (COMNAVAIRFOR 2013). For example, all aviation electronics technicians (AT) are part of the avionics branch, which combines with the ordinance (AO) and electricians (AE) branches to form the AV/ARM division (COMNAVAIRFOR 2013). Each division then reports to the maintenance control, which serves as the manager of all maintenance activities within the unit (COMNAVAIRFOR 2013). Parallel structures for material and production control also exist, but these areas fall mostly outside the scope of this analysis and will be discussed only where necessary and not in detail. Figure 1 shows the architecture of the maintenance department.

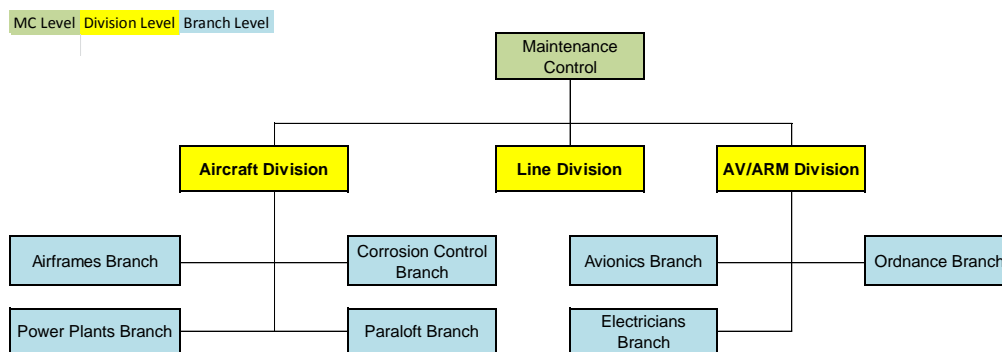


Figure 1. Maintenance Department Architecture Example.

2. Aircraft Inspection and Repair Process

The final portion of the NAMP to be explored is the aircraft inspection and repair procedures. Inspections and repairs are the most labor intensive portion of the NAMP at the operational level. Inspection and repair serve as the major sources of preventive and corrective maintenance. This discussion of inspections and repairs is not exhaustive, but provides a basic overview of both preventive and corrective maintenance activities. These areas serve as the baseline for the comparison of alternatives to the current NAMP that will follow in subsequent sections.

a. *Scheduled Maintenance*

Most of the preventive maintenance mandated by the NAMP is scheduled based on flight hours, operating hours or calendar days. The goal of each operational squadron is to minimize the number of concurrent inspections taking place at any time (COMNAVAIRFOR 2013). For simplicity sake, the focus remains on the two primary scheduled maintenance regimes covered in this thesis: special inspections and phase inspections. Special inspections are primarily related to elapsed time, flight hours, or cycles of events. The specific tasks carried out on each special inspection depend on the platform being inspected, but the time interval for special inspections are constant across all airframes (COMNAVAIRFOR 2013). Table 1 includes the MH-60S specific special inspections and their intervals.

Table 1. MH-60S Special Inspections (after NAVAIR 2013).

7 Day	56 Day	360 Day	546 Day	525 Hour
14 Day	112 Day	364 Day	728 Day	700 Hour
28 Day	180 Day	365 Day	30 Hour	1000 Hour
30 Day	224 Day	448 Day	60 Hour	

In addition to these inspections that are based on time intervals, phase inspections are conducted at regular intervals to inspect all aircraft systems. Currently, the MH-60S uses a 700-hour phase cycle in four inspections occurring once every 175 flight hours (Naval Air Systems Command [NAVAIR] 2013). The phases are labeled as A, B, C, and D, and Table 2 details the specific maintenance performed during each phase inspection.

Under the current NAMP, all scheduled maintenance is divided into more manageable parts, with all aircraft components inspected once every 1000 flight hours or 728 days (approximately 2 years). The NAMP also provides for deviations from the established cycles to accommodate continued operations when necessary (COMNAVAIRFOR 2013). Additionally, maintenance schedules at the operational level are contained in the monthly maintenance plan (MMP), where each command details its plan for all scheduled maintenance activities for the next month (COMNAVAIRFOR 2013).

Table 2. Phase Cycles. (after NAVAIR 2013)

Phase	Maintenance	Hours	Assist Hours
All		79.5	91.4
	Hydraulic System Sampling	1.3	1
	Utility Hydraulic System Sampling	1.3	1
	Flight Control Bearings	1	1
	Access Panels Removal and Inspection	8.7	7.7
	Airframe Inspections (Cabin, Transition Section, Tail Cone, Main Rotor Pylon, Tail Pylon)	17	17
	Flight Control Cables	1.5	1.5
	Tail Landing Gear Shock Strut	1	1
	Main Rotor Blades	1.3	1
	Rotor Brake	0.5	0
	Power Plant System	2.4	2.1
	Air Turbine Starter	1	0
	Fuel System	0.5	0.5
	Main Rotor Head	6	10
	Main Module	2.3	0
	Main Gear Box Radiator	0.5	0
	Engine Output Shaft	2.8	2.5
	Auxiliary Power Unit	0.6	0.1
	Disconnect Coupling	2.8	2.3
	Tail Rotor PCR Bearings	0.5	0
	Post Phase Vibration Analysis	16.5	32.5
	Fuel Dump System Operational Check	2	3
	Flight Controls	1	1
	Main Transmission Chip Detectors	1.5	2
	Fire Extinguishing System	0.7	0.5
	Rescue Hoist and Cargo Hook	0.7	0.7
	Stabilator	2	2
	IRCM	0.4	0
	FLIR	1	0.5
	Mission Tape Recorder	0.7	0.5
A/C		33.9	29
	Windshield and Wipers	0.6	0
	Flight Control Cables	0.5	0.5
	Airframe Inspections (Cockpit, Cabin and Tail Cone/Pylon)	6	6
	Torque Shaft Bearing Supports	0.8	0
	Main Landing Gear	5	5.5
	Tail Landing Gear	2.5	2.5
	Main Rotor Head	2.6	2.6
	Swashplate Assembly	1.5	1.5
	Power Available Spindle Cables	0.5	0
	No. 1 Engine Load Demand Spindle Control Cables	0.7	0.7
	Engine Pneumatic Starters	1	1
	Auxiliary Power Unit	1.5	0
	Fuel Cell Ballistic Ring	0.5	0
	IGB/TGB Oil Change	2	2
	Tail Rotor Assembly and Directional Flight Controls	7	5.5
	Tail Rotor De-Ice Slipping Bush Block	0.7	0.7
	Data Bus System	0.5	0.5

Phase	Maintenanace	Hours	Assist Hours
B/D		17	10
	Nose Vibration Absorber	1.8	1.5
	Vibration Absorbers	4	2
	Tail Landing Gear Structure	0.7	0
	Flight Controls	1.5	1.5
	Primary Servo Bolts	1	1
	Environmental Control System	1	0
	Main Rotor Head	1	1
	Engine Exhaust	2	0
	No.2 Engine Load Demand Spindle Control Cables	0.7	0.7
	Tail Drive Shaft	1.3	1.3
	Tail Rotor Assembly	1	0
	Pitot Static System	1	1
A			
	No Additional Inspections		
B		4.7	3.7
	Main Rotor Dampers	1	1
	Blade Assembly	1	1
	Main Rotor Spindle and Hinge/Hub Assembly	1.7	1.7
	Main Gear Box Radiator	0.7	0
	Main Rotor Blade Assembly	0.3	0
C			
	No Additional Inspections		
D		57.5	63.8
	Flight Control Mixer	1.5	1.5
	Main Rotor Blade and Damper Removal	2	3.4
	Main Rotor Blades and Tip Caps	2	0
	Main Rotor Damper System Drain	2.5	5
	Main Rotor Blade and Damper Installation	3	4.4
	Environmental Control System	1.5	0
	Main Landing Gear	1.5	1.5
	Tail Landing Gear Shock Strut	1	1
	Main Rotor Head Sub Assembly	10	14.5
	Main Rotor Elastometric Bearings	4	4
	Main Rotor Spindle and Hinge	21.5	21.5
	HIRSS	3	3
	Main Rotor Head Slip Ring	1	1
	Main Rotor Functional Checks	2	2
	Main Rotor Damper System Drain	1	1
	Phase	Hours	
	A	233.8	
	B	206.3	
	C	233.8	
	D	319.2	

b. Corrective Maintenance

Corrective maintenance frequency is established by the need to correct discrepancies to aircraft. The basis for the corrective maintenance effort is both the inspection process and the use of unscheduled maintenance action forms (MAF). (COMNAVAIRFOR 2013) A MAF is a document that is initiated for each maintenance action, whether scheduled or unscheduled, and provides the necessary information for the

maintenance to be performed. For unscheduled maintenance, each MAF details the condition which triggered the maintenance action, the corrective action taken, and the person and work center used to correct the discrepancy (COMNAVAIRFOR 2013). Each MAF contains more than this information, such as job number, system type, etc., but these details are outside the scope of this analysis. MAFs may be written by either aircrew or maintenance personnel, and are considered current records for the next 10 flights on each individual aircraft. These MAFs form the record of all maintenance performed on an aircraft within the last 10 flight cycles, and they are further kept in historical record for at least 12 months after the maintenance action was performed (COMNAVAIRFOR 2013). The current system used by most commands to generate maintenance actions and manage the maintenance effort is Naval Aviation Logistics Command Management Information System / Optimized Organizations Maintenance Activity (NALCOMIS/OOMA). NALCOMIS/OOMA is currently in use at every squadron operating the MH-60S, and the specifics of NALCOMIS/OOMA system are found in the NAMP, Chapter 13 (COMNAVAIRFOR 2013). For the purposes of this study, it need only be recognized that NALCOMIS/OOMA is the extant organizational system, so it will not be explored in depth.

Now that the relevant sections of the NAMP have been summarized, an important question must be answered with regard to this study. How well does the NAMP perform today, and what is the value of implementing the performance improvements that are discussed in the NAMP? The answers to these questions speak to the relevance of this thesis and will help form the theoretical framework that will be developed in Chapter III. First and foremost, it must be determined if the NAMP is a useful process that meets the needs of the Navy. Second, since the NAMP provides its own amendment process, what most needs to change about the NAMP to ensure success into the future. Finally, since the NAMP favors RCM at the operational level as the preferred “performance improvement” solution, do RCM processes provide the best alternatives for the current processes. These questions are addressed in Chapter III, as they deal directly with the purpose of this study. In closing, it is important to note that the NAMP currently relies on the use of labor intensive inspections and repairs to meet the system-level needs of

aircraft maintenance. With the new world of constrained budgets and continued global interaction, this process may require a significant change to remain a valid solution to stakeholders' needs.

III. LITERATURE REVIEW

With the recent draw down of forces from Iraq and Afghanistan, the DOD has seen a shift in priorities and now faces many new budget realities. The needs to reduce both current and future budgets, as well as the requirement to continue the development of capabilities, have led to a series of studies involving weapon systems and associated processes. Within this context, a focus has been put on legacy systems, as the long service life of many systems creates a need to improve performance and reduce life cycle costs prior to the next generation of weapons entering service.

The Navy in particular has examined this reduction in life cycle costs, as evidenced by the *Naval Aviation Vision 2020*. This publication, released in 2005, describes the future needs of the Naval Aviation Enterprise (NAE) and lays out the vision of the future aviation force in the year 2020. The NAE is said to be measured by one simple metric: “aircraft ready for manning at reduced cost” (Taylor et al. 2005). To meet this metric, the NAE put forth a focus on cost-wise readiness, buying higher quality components to improve readiness, reducing the time that systems spend in maintenance, increased reliability and implementing process efficiencies (Taylor et al. 2005). The NAE focus serves as the statement of need for all aviation systems and provides the metrics that determine the success of a system.

The aim of this thesis is to determine how well the maintenance process responds to the need for aircraft designs that are ready for production at a reduced cost. The objective, therefore, is to determine how well a legacy or developmental system satisfies this metric in relation to viable alternatives. This chapter develops the viable alternatives to the current processes that were described in Chapter II. The literature review explores the results of published studies that are related to the current state of naval aviation and present the theoretical framework for this study. Through this process of reviewing the literature, a framework was created that related the need for this analysis, the tools used to evaluate alternatives, and the ways in which the results were evaluated. This method creates a clear means for collecting data, evaluating results and interpreting conclusions that follow in successive sections of the thesis.

A. GAP ANALYSIS

1. Necessity of Gap Analysis

When considering the current state of the Naval Aviation Enterprise, it is important to understand both its present and likely future composition. As discussed in Chapter I, reductions in future budgets will force a change in the way Naval Aviation does business. Following the end of the Cold War, there was a large shift in the needs of the DOD as countering the Soviet Union was no longer the focus of American foreign policy. The composition of the armed forces changed greatly over the next two decades away from a European-centric strategy. According to the *New York Times*, by 2014, the number of U.S. troops had decreased from 400,000 during the Cold War to a current force of about 67,000 (Cooper and Erlanger 2014). At the same time, the number of aircraft had decreased from approximately 800 at the end of the Cold War in the early 1990s to about 172 today (Cooper and Erlanger 2014). The cuts in Europe have left the Navy with fewer forces, numbering approximately 7,000 sailors and marines with no aircraft carriers stationed in the Mediterranean (Cooper and Erlanger 2014).

Based on the nature of the geopolitical changes that took place between 1990 and 2014, this shift was to be expected. The shift in forces away from Europe also shows that plans for weapons systems need to be flexible and adapt to changing realities. Many weapons systems that form the backbone of the modern U.S. Navy were developed to fight the Soviet threat, including the H-60 helicopter. Modern weapons systems need to be able to be modified to engage threats that exist in the present that might not have been the focus of design decisions in the past.

U.S. combat systems have required great evolution to meet a much different threat than seen even during the first Gulf War in 1991. The *Naval Aviation Vision 2020* points out the change from the force composition during the first Gulf War to the forces that fought in Iraq and Afghanistan. Over 93 percent of Navy and Marine sorties in Operations Iraqi and Enduring Freedom involved the use of precision guided weapons, which was a significant increase from the first Gulf War (Taylor et al. 2005). Due to this change to a more precise type of warfare, weapons systems have become more costly to

both acquire and maintain. As was discussed in Chapter I, however, there are severe budget limitations that will constrain the DOD for the foreseeable future. This dichotomy between the increasing cost of weapons systems and the decreasing resources available for their production and maintenance is the primary trade space available to military decision makers.

The NAE has understood for nearly a decade that the cost of acquiring weapons is too high. This fact is conveyed through the use of “reduce the cost of doing business” as one of its strategic readiness goals (Taylor et al. 2005). This statement is almost hopelessly board in dealing with the costs of equipping the military. Costs associated with manning and acquisition decisions dominate the cost calculations of the military, but these are not the only areas where cost savings can be achieved.

To reduce the cost of business, the NAE has focused on providing more capability per dollar in the fleet and increasing the efficiency of processes by both upgrading and modernizing the fleet (Taylor et al. 2005). The priority to modernize and upgrade the fleet has an enormous significance, since the entire fleet cannot simply be replaced with new ships or aircraft. One need look no further than the enormous cost of the F-35 project to understand that creating completely new aircraft systems is likely cost prohibitive in the current fiscal environment. The focus then shifts to ways to save costs using the people and equipment that the Navy already has.

To achieve cost savings, changes can be made in the composition of the force in terms of people, weapons, and processes. Manning composition, although extremely important, is outside the boundaries of this study. This thesis will seek to find ways to reduce manning requirements, but questions related to how to best populate aviation units are not the focus. Instead, the emphasis will remain on possible cost savings achieved by altering the processes surrounding legacy systems. Through improving the efficiency of systems already in place, cost savings can be achieved today that allow for the use of greater resources for future systems.

With this focus on cost in mind, legacy systems must be modernized in ways that both save costs and extend the system’s lifecycle. This modernization poses two

enormously important questions: how well is Naval Aviation meeting the goal of increasing efficiency in order to upgrade the fleet? Furthermore, has the Navy maximized its use of resources today or do areas exist where resources can be conserved without a negative impact on combat readiness? If the Navy has not used all means available to increase efficiency without a negative impact on combat readiness, then new processes and functions must be developed to achieve this greater efficiency.

Table 3. *Naval Aviation Vision 2020 Strategic Readiness Goals.*

Strategic Goals
Balance Current and Future Readiness
Reduce the Cost of Doing Business
Enhance Agility
Improve Alignment
Attain and Maintain Visibility Across the Enterprise

Table 4. *Naval Aviation Vision 2020 Strategic Readiness Actions.*

Strategic Actions
Prioritize capabilities, define requirements, and efficiently acquire and prepare relevant and optimally sized Naval Air Forces that satisfy our nation's warfighting needs
Operate with a common set of linked processes, each having an owner, metrics, and an action plan that drives continuous improvement
Install processes that are repeatable, agile and predictive
Manage performance and financial metrics as the common Enterprise language
Execute a Continuous Improvement Program designed to define, measure, improve and control NAE processes, to include Human Capital, acquisition, training, and materiel readiness
Develop quantifiable outcome metrics to measure our success and cultivate improvements that positively impact current and future naval readiness

Since Naval Aviation seeks to become more efficient, how does the NAE plan to achieve the goal of “reducing the cost of business as usual?” According to the *Naval Aviation Vision 2020*, relevant actions from Table 4 must be taken to meet the NAE's combat readiness goals from Table 3 (Taylor et al. 2005). This combination of readiness goals and actions not only lays out the ways in which the NAE hopes to reduce the cost to train, equip and operate the fleet, but also provides the philosophical basis for this study.

In systems engineering terms, the six actions from Table 4 serve as the top-level user requirements that the NAE must meet to achieve success in “reducing the cost of doing business.” The user’s requirements inform the analysis needed to determine how well each of these areas is satisfied by current processes and to identify shortfalls that exist. Therefore, a capability gap analysis is used to measure the fleet’s success in meeting the NAE’s requirements. Since this vision is nearly a decade old, it is also likely necessary for a reassessment of readiness goals, since the fiscal environment of 2005 was much different than that of 2014. Since the 2005 goals were meant to shape the force in 2020, they still remain relevant today but their relevance is quickly approaching its end.

Since the NAE has set the requirements for future success, it is important to understand how these requirements are quantified and success is measured. This understanding requires that the term success be defined in a way that can be measured and compared between possible outcomes. Since the NAMP, as discussed in Chapter II, focuses on creating a system of constant “performance improvement,” any measurement of success should be able to determine the value of improved performance. (COMNAVAIRFORINST 2013) However, performance improvement is a vague and there are myriad ways that improvement can be interpreted. Additionally, many of the variables related to performance improvement have competing interests, so no improvement scheme can assure unanimously positive results related to all aspects of any system. To maintain a narrow focus, the basis for this research is the writings of the NAE that set priorities for requirements.

As can be seen in Table 3, the five strategic goals are put forth as essential ingredients for performance improvement across the lifecycle of aircraft development and sustainment. Furthermore, the series of strategic actions presented in Table 4 provide a basis for developing metrics to measure success and meet the requirements from Table 3. Therefore, an appropriate framework must be created that accurately applies the principles established in Tables 3 and 4. This framework provides the best way to measure the outcome of any performance improvement regime.

2. JCIDS Process

The JCIDS process provides the means for determining what prioritized capabilities are required by operational forces. The following text from the JCIDS manual's section on requirements identification and document generation provides the justification for gap analysis:

Services, Combatant Commands, and other DOD Components conduct Capabilities Based Assessments (CBAs) or other studies to assess capability requirements and associated capability gaps and risks. In the case of Urgent or Emergent operational needs, the scope of the assessment may be reduced to an appropriate level to determine the capability requirements in a timely manner...Capability requirements and capability gaps identified through CBAs and other studies are traceable to an organization's assigned roles and missions, and, to the greatest extent possible, described in terms of tasks, standards, and conditions in accordance with references bb and cc...Any capability requirements which have significant capability gaps typically lead to an ICD which can then drive development of capability solutions which are materiel, non-materiel, or a combination of both. Urgent operational needs typically lead to a JUON or DOD Component UON document. Emergent operational needs typically lead to a JEON or DOD Component UON document. (Department of Defense [DOD] 2012, A-1)

For the purpose of this study, the Capabilities Based Assessment is used to facilitate the capability gap analysis of the MH-60S maintenance process. The specifics of the CBA are detailed in Chapter IV, with its purpose being to determine the extent of the capability gap related to CBM in the MH-60S. The JCIDS further explains how the results of a CBA should be used to drive solutions to close the identified gaps (DOD 2012). Further, the selection of a single airframe, the MH-60S, is justified as the lack of CBM could constitute a joint emergent operational need (JEON). For this thesis, the terms capability gap and JEON are defined the same as in the JCIDS manual (10JAN2012). Capability gap means the inability to execute a specific course of action. JEON refers to urgent operational needs that are identified by a Combatant Command as inherently joint and impacting an anticipated or pending contingency operation (DOD 2012).

Any MH-60S CBM capability gap is emergent and not urgent since the current NAMP process is capable of maintaining the aircraft to meet operational needs. On the contrary, the elevated cost in terms of man power and cost of the extant maintenance process does constitute a threat to future operations. For this reason, the capability gap meets the JCIDS standard for an emergent threat. The JCIDS process and its application to the gap analysis are explored in more detail in Chapter IV.

3. Value Engineering and Earned Value Management

The MH-60S presents a suitable program for the study of performance improvement. It was produced with a series of variants, generally expressed with many additions to the airframe since the first release. All of the variants that have been produced are being operated currently, so comparison of the variants can be made. The first question is: what should the framework for making comparisons look like? The second question is: what are the most important comparisons to be made? The answer to these questions, at least in terms of the MH-60S, lies in the principles of value engineering and gap analysis, and the work of Langford and Franck (2009).

In their discussion of Earned Value Management (EVM), Langford and Franck provide that the number one goal of EVM is to “suggest how management can obtain the best-value solution for the taxpayer’s money.” Furthermore, they define the application of gap analysis to EVM as such:

If managers perceive a deficiency or a desired goal that differs from that which the actual work auspicates, there could exist a basis for gap in intentions versus what has been achieved, and, therefore, a desire to close that gap. The goal of Gap Analysis with regard to EVM is to maximize the difference in achieving cost-effectiveness by employing one (or more) of possible management strategies versus others out of the set of alternatives. (Langford and Franck 2009, 4)

Since the goal of EVM is to determine the best value for the use of resources and gap analysis provides a way for managers to close the gap between desired and actual performance, Langford’s and Franck’s research speaks directly to the problem of how to measure performance improvement. Expanding upon this point, Langford and Franck explain that the difference between what a manager has in a project versus what a

manager wants in a project constitutes a “Value Gap” (Langford and Franck 2009). This value gap then is the difference between desired and actual performance in terms of what is important to the manager (Langford and Franck 2009).

According to the NAE, the factors that are important to a naval aviation manager are found in Table 3. The chief goal when combining the NAMP and *Naval Aviation Vision 2020* is to improve performance constantly while simultaneously reducing the cost of doing business. This improvement means that a process change can only be deemed successful or useful if it provides more capability for less cost, which Langford and Franck define as management achieving “more for less” (Langford and Franck 2009). For this reason, the purpose of any change in process must be designed to deliver more capability for less cost, and all changes should be evaluated on this basis.

Although the evaluation of “more for less” seems like a simple proposition to apply, it is difficult to easily measure both the cost and capability provided by a change in process. This difficulty is due to the fact that many costs, such as labor, are not easily monetized in dollars used for a particular task. The Navy does not pay each of its workers on an hourly basis, so the cost of using labor is generally fixed for a given time period when the pool of workers is fixed. Therefore, the best measurement of cost is to calculate the amount of time that is used to perform certain tasks. If the amount of time, measured in labor hours, has an aggregate decrease as a result of a new process, then the process could be said to lower the cost of doing business. This assumption is also true of replacement parts usage, as any process that lowers the number of parts used can be considered less costly. In terms of capability, it is difficult to create metrics which can be estimated and compared to status quo processes. Therefore, capability can be measured in terms of both safety and aircraft availability, which can be reasonably measured using existing tools. In terms of the NAE’s vision, an increase in capability can be viewed as having more aircraft available for use at any given time while having fewer mechanical issues that compromise flight safety.

With all of these standards in place, the final step is to find a framework for evaluating process changes that provides managers with the ability to compare new process ideas to extant processes. Langford and Franck provide such a framework, and it

can be tailored to meet the needs of this analysis. In their work on Value Gap Analysis (VGA), Langford and Franck propose the following application of VGA to manager's decisions:

By developing the theory of Value Gap Analysis into a form that can be applied in a clear and consistent manner for managers, (1) value metrics can be compared with Earned Value; (2) worth metrics can be applied to a critical examination of foundation data; (3) risk metrics can be used to interpret the relevancy of data; (4) an enterprise framework (which displays worth and risk metrics) can be used to illustrate context at a given time; and (5) assumptions can be scrutinized definitively. (Langford and Franck 2009, 11)

Langford and Franck provide a further explanation of the ways that VGA can be applied to work in the following passage:

We define Value Gaps in terms of the functional requirements, their performances, and their losses due to those performances. Further, all Value Gaps can be characterized in terms of capability of human capital. By reference, EVM was implemented to specifically address measuring gaps between planned and actual performance. But since not all performance gaps require a human capital solution set, VGA must be modified. Changes or enactments of policy, organization, training, materiel, leadership and education, and facilities are considered candidates to close Value Gaps. These factors are usually formally evaluated before recommending the start of a new development effort. The result is that the process of managing work tasks is functionally decomposed to allow the assessment and identification of Value Gaps. (Langford and Franck 2009, 13)

This excerpt in many ways provides the theoretical foundation for this study. Through a tailored process of Value Gap Engineering that focuses on changes to policy, any program can identify and close the gaps in attained value that exist. Langford and Franck focus mostly on the ways in which a project can implement these changes early in the development process to create value during acquisition, but the principles of their research apply equally well to a program such as the MH-60S that has been in service for several years. Langford and Franck provide a thorough discussion of value, worth, and risk and propose equations for both value and worth that can be applied to this analysis (Langford and Franck 2009). These equations, presented in Figures 2 and 3, provide the

basic relationships between the value, worth, and risk measures. Langford and Franck introduce the idea of quality affecting the value of a process

$$V_F(t) = \frac{\sum P(t)}{I(t)}$$

Figure 2. Value Equation (from Langford and Franck 2009, 16).

$$W_F(t) = V_F(t) * Q(t) = \frac{\sum P(t) * Q(t)}{I(t)}$$

Figure 3. Worth Equation (from Langford and Franck 2009, 19).

The value (V) of any function (F(t)) can be measured by the sum of all performances (P(t)) divided by the investment (I(t)) made in the function over any given time period (t). The worth of a system, defined by Langford as the value to include any possible loss incurred as the result of a given performance, is measured in terms of the product of the value and the possible loss function denoted by quality (Q(t)) (Langford and Franck 2009). To apply these functions to the NAE example developed in this chapter, value is the ratio of labor performance to investment, and worth is the application of this interaction to include the quality either gained or lost in the process. These two equations provide the general framework for measuring outcomes in terms of altering processes with the NAE framework that was previously discussed. In Chapters IV and V, the application of these equations to the MH-60S maintenance program will be explored in more depth and definite metrics for value and worth will be proposed and discussed.

B. BOUNDARIES

Boundaries refer to the functional, physical, and behavioral limits of the research, and an understanding of each type of boundary is required as part of the Gap Analysis. As with any systems engineering analysis, the functional boundaries define the problem space and allow for the derivation of the physical and behavioral characteristics of the problem. With the functional boundaries of the study established, the physical boundaries can be explored to determine what physical components will be analyzed. Finally, the behaviors of the system and its components can be discussed to determine the limits of what actions will be analyzed.

1. Functional Boundaries

In functional terms, this study was limited to an analysis of aircraft maintenance systems under the extant regime and alternative conditional-based maintenance structure. The NAMP explains the three top-level functional requirements for aviation maintenance at the O-level. As was discussed in Chapter II, the top-level functions are: “maintain operational capability”, “document maintenance”, and “improve processes.” As the discussion in Chapter II suggests, the domain of this research was the operational level maintenance practices. However, the scope of this effort was narrowed further to the relevant functions related to scheduled maintenance as part of the NAMP. More specifically, the Gap Analysis was bounded by the Phase Maintenance and Special Inspections functions. These maintenance functional areas provided a means to inspect components and certify the airworthiness of aircraft based on time in days and the number of hours flown.

Using the three top-level functions, the second level functions related to phase and special inspection can be derived. From the top-level function “maintain operational capability”, the second-level functions of “determine system discrepancies”, “correct system discrepancies”, and “ensure safety” are derived. The other two top-level functions “document maintenance” and “improve processes” are used to derive the second-level functions “provide monitoring capability”, “maintain record of maintenance actions”, and “limit resource usage.” By setting the functional boundary along these lines,

the research was then focused on how well any vetted maintenance process accomplishes these functions. Since data on resource usage is available for both IMDS and non-IMDS capable aircraft, setting these functional boundaries allowed for a useful comparison of maintenance processes. Figure 4 shows the decomposition between the top-level second-level functions.

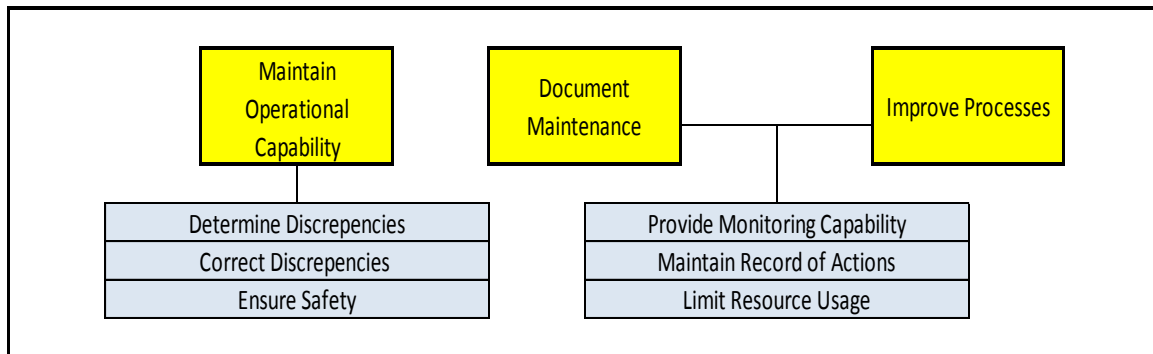


Figure 4. Functional Decomposition.

2. Physical Boundaries

The physical boundaries of the analysis are limited to the physical systems found on the MH-60S along with the people and equipment used to conduct maintenance on the aircraft. Since the purpose of the NAMP is to standardize maintenance across all Navy aircraft, nearly a limitless number of comparisons can be made. Since each individual platform, i.e., jets, helicopters, and maritime aircraft, has unique maintenance systems, it is impossible to make relevant comparisons between platforms. Therefore, a single platform must be selected, which is in this case a helicopter.

The Navy currently flies a single helicopter model, the H-60, but several different series variants with a variety of sub-systems and mission sets. For this reason, a single series, the MH-60S, has been chosen to limit the scope of the research. The MH-60S provides an excellent platform for study, as multiple variants exist, and all have the capability to support IMDS. At the same time, IMDS is not installed on all aircraft, so there is an excellent space to be explored between CBM capabilities and legacy capabilities. The physical boundary for CBM capability will be the on-board systems as

well as ground support systems related to IMD-HUMS. The Gap Analysis will assess not only the gaps between legacy maintenance usage and CBM capability, but also any capability that is needed for CBM but not provided by IMD-HUMS. That is to say, determine the actions that IMDS can and cannot replace that are part of the NAMP.

3. Behavioral Boundaries

The behavioral boundaries are defined by the actions performed to conduct maintenance on the MH-60S based on the functions and physical objects involved with the maintenance as well as the lack of the required functions or physical objects. These behaviors will be limited to those conducted by maintenance personnel to perform the necessary maintenance functions listed above. The scope of behaviors is also bounded by the actions taken by operators to use the IMD-HUMS system effectively to achieve a CBM capability. Finally, the behavioral boundaries are defined by the time frame in which the actions studied take place.

In this case, the relevant maintenance actions took place between July 2013 and August 2014 within the Helicopter Sea Combat Wing, Pacific (HSCWP). The time frame is limited to the actions conducted for one year since each squadron is required to maintain a record of all flights and maintenance actions for 12 months for each aircraft in their inventory. Three squadrons, one carrier based, one expeditionary, and one fleet readiness squadron will be analyzed. These squadrons constitute one of each type of squadron within the HSCWP, with each performing a variety of missions. In total, these missions constitute all the mission sets performed by the MH-60S and provide an accurate cross section of maintenance activities. These boundaries clearly define “the who, what, when, where and how” of the gap analysis and clearly define the scope of the problem. The boundaries will be explored further as part of the gap analysis in Chapter IV.

C. CONDITION-BASED MAINTENANCE

To understand the possible gains that can be achieved by conducting a gap analysis and implementing value engineering to Naval Aviation processes, there must be an examination of both the current process and viable alternatives. The NAMP, which provides the structure of the current maintenance program, was discussed in length in Chapter II. However, the Navy has been focused on improving the NAMP for several years and has looked for a preferred alternative to the current maintenance process based on time cycles. In many ways, the Navy, as was noted in the discussion of the *Naval Aviation Vision 2020* in the previous section, does not view the current process as sufficient to meet its future needs. On the other hand, the Navy does present a preferred alternative in the form of Condition-Based Maintenance.

CBM has been at the forefront of the Navy's effort to modernize its force for nearly two decades, and has become the primary maintenance goal for both new and legacy systems. With the introduction of the OPNAVINST 4790.16 series, the Navy detailed the scope of CBM activities thusly:

This instruction applies to acquisition, logistics, and maintenance activities for new and legacy programs. CBM concepts all active and reserve naval ships, aircraft, and the systems associated with them, as well as the infrastructure that supports them...

The purpose of the CBM strategy is to perform maintenance only when there is an objective evidence of need, while ensuring safety, equipment reliability, equipment availability, and reduction of total ownership cost. The fundamental goal of CBM is to optimize readiness while reducing maintenance and manning requirements." (CNO 2007, 1)

This statement in many ways serves as the mission statement for all maintenance programs within the Navy. This passage also helps to clearly define the boundaries of any weapons system and its associated support activities. Since the Navy has a goal for the future in mind, it seems that any gap analysis should be centered on this chosen path and assess where gaps exist and the value associated with closing these gaps. These issues, including the specific applications to the MH-60S and the boundaries of this study will be

discussed later in this chapter. However, a better understanding of CBM, its history, and components is required before an assessment of its efficacy is made.

1. CBM Literature

Since CBM is the preferred structure for maintenance programs Navy wide, it is important to review studies that have measured its usefulness. CBM is not only used by the military, but by other manufacturers in the private sector. For example, John Deere has converted from its legacy “periodic maintenance” effort, which is similar to the NAMP cycle, to a condition-based maintenance process (Deere 2014). Deere has used CBM to achieve “a maintenance strategy aimed at extending machine life, increasing productivity, and lowering your daily operating costs,” which mirrors the goals of the Navy’s CBM program (Deere 2014). A company simply stating that CBM is better than time based maintenance does not make the statement true, so an evaluation of current literature on CBM provides a much better understanding of the efficacy of CBM in general.

The relevant literature provides two important points of view for CBM: the structure and goals of DOD CBM programs and the effectiveness of current CBM programs in meeting these goals. First, the CBM programs were explored to gain a better understanding of the goals of the DOD and Navy for CBM programs. Following this investigation of CBM programs, a more thorough investigation of CBM usage to date within the DOD was examined. Although CBM is not exclusive to the defense industry, the focus of this study will remain within DOD systems. Although some commercial programs could be relevant, the difference in performance standards for equipment between private companies and the DOD makes comparison to the MH-60S more difficult. Therefore, the focus will remain on DOD CBM programs to maintain a more narrow scope for this investigation.

Within the DOD, condition-based maintenance is most commonly defined as part of the CBM+ (CBM Plus) program. CBM+ for maintenance operations is most clearly outlined in two publications: DODI 4151.22 Condition-Based Maintenance Plus for Material Maintenance, and the Condition-Based Maintenance Plus DOD Guidebook.

DODI 4151.22 contains the policy and implementation guidance for all DOD CBM programs. This publication provides a higher level view of CBM than the OPNAV and AIRNAV instructions that have been previously discussed. The DOD policy guidance for legacy program maintenance is presented, which states that CBM should be “integrated in current weapon systems, equipment, and materiel sustainment programs where it is technically feasible and beneficial” (DOD 2012). This statement is particularly relevant to this study, as Enclosure 2 of the same document states that the decision to implement a CBM program is based upon “Continuous process improvement initiatives in accordance with DODD 5010.42” and “Technology Assessments” (DOD 2012). This guidance lends itself very nicely to assessment using gap analysis within the process improvement framework established in both the NAMP and Navy CBM policy.

The other important aspect of the 4151.22 is the guidance provided to the individual services in terms of CBM implementation. In the responsibilities section, each military department is tasked with both reviewing the effectiveness of CBM programs and including CBM solutions for new and legacy system maintenance (DOD 2012). This section serves as the requirement for the Navy to develop its own CBM program and to make maximum use of CBM where possible. Additionally, CBM is used as the preferred method for all maintenance activities and the Navy is tasked with finding ways to increase the usage of CBM wherever possible.

Expanding on the DODI 4151.22 guidance, the Condition-Based Maintenance Plus DOD Guidebook provides a more in-depth look at CBM programs and directives. The CBM Guidebook includes an overview of all DOD CBM efforts and establishes the necessity for changing the ways that maintenance has been done in the past. The most relevant section in this study is Section 6, Measuring Success (DoD 2008). Measuring Success provides metrics for both implementation and operation of CBM programs, including the most relevant ways to track the effectiveness of a CBM program already in place. More specifically, the following guidance is provided for measuring an operational CBM program:

One of the key challenges at the DOD and Service level is to gauge and map how CBM+ is progressing. A common end state is improved

maintenance from the maintainer's perspective as well as the warfighter's. CBM+ implementers should track a small number of metrics over the long term to assess whether CBM+ improvements are enabling a more effective maintenance process. (DOD 2008, 6-3)

According to the concept outlined in this passage, the MH-60S is nearly a perfect fit for an analysis of the progress of a CBM program. This fit is due to the fact that IMD-HUMS has been implemented to facilitate CBM on some, but not all aircraft, and there is a long time frame of data collected that can be analyzed based on simple metrics. Specific metrics, such as labor hours or parts usage, can be measured using both a CBM capable aircraft and a baseline aircraft without CBM. These metrics will be discussed more extensively in Chapter IV.

These references are not exhaustive in their coverage of CBM programs within the DOD. For the scope of this thesis, however, the combination of these CBM resources and the guidance in the JCIDS Manual provides more than enough guidance to create a useful evaluation of CBM capability. DODI 4151.22 and the DOD CBM+ Guidebook provide a framework for judging CBM programs that can be applied to the investigation of the MH-60S. The most important value provided by these CBM directives is a better understanding of what constitutes a relevant CBM study. A relevant study of CBM capability is one that applies the systematic application of metrics to determine a reasonable alternative that includes greater CBM capability. Armed with this information, each military branch can implement overarching CBM programs and individual weapons systems can be assessed for compliance with CBM goals.

Condition-based maintenance has been positioned in DOD literature as the most important part of cost effectiveness maintenance processes in a resources constrained environment. CBM has been a large part of the DOD's future vision for nearly two decades, but CBM has not yet become ubiquitous within maintenance departments throughout the military. The experience of the MH-60S in particular provides a great example of disconnect between the status quo and desired CBM end state. This reluctance to embrace CBM in practice is most likely due to the organizational inertia of the current NAMP. Everyone involved in naval aviation maintenance has used the NAMP for the entirety of their career, so conversion to CBM will require a change in

culture that has yet to occur. The Navy released its first CBM directive in 1998, but, as can be seen in the NAMP discussion from Chapter II, the conversion away from time-based maintenance has yet to occur. For this reason, it is important to look at studies of the CBM process in use. These studies help provide guidance as to how effective CBM has been at meeting the resource savings goals that have been promised in DOD literature. Through the use of study, the value of CBM is determined and culture changes can be initiated.

Before considering the results of past studies that investigated the effectiveness of CBM, it is important to note that this study uses a different construction for determining CBM efficacy than others cited herein. The work of studies conducted by Pandey and van der Weide, Wegerich, Coats et al., and Bechhoefer and Bernhard focused more on the engineering of CBM enabling systems. This difference in approach does not mean that studies similar to this one do not exist, but simply that CBM-enabling systems have been a greater focus than CBM processes in a large portion of the literature. It is possible to gain a perspective on the efficacy of CBM systems and data analysis techniques which have been used in other studies by viewing the maintenance systems as the systems that they are. From the systems perspective, the detection and report of a condition that manifests in a maintenance event represents the *currency* of knowledge about the aircraft's well-being. From that systems perspective, the literature can be analyzed and evaluated for pertinent information that helps characterize the results presented.

This lack of focus on process does not mean that other studies have no value to this investigation. On the other hand, little guidance is available from other engineering sources to help shape the design of this study, which relies more heavily on DOD directives for its construction. There has been significant study on CBM related to Operations Research which does involve the economics of CBM. These studies do not directly address the systems engineering aspects of process design, again limiting the direct relation to this study. Therefore, the approach for this thesis is informed by these other studies and combines elements of both engineering and operations research into its construction.

The idea that CBM is less costly than maintenance involving inspection cycles is supported within risk literature in regards to large, complex systems. In one such study by Pandey and van der Weide (2009), a comparison of preventive maintenance schemes based on constant monitoring and periodic inspection was made. In their work, Pandey and van der Weide attempt to construct a discounted cost distribution to apply to systems that are damaged by shocks or transients that occur at random times. The results revealed a lower than expected cost and failure rate of large systems which are approximated by a non-homogenous Poisson process when monitored with continuous inspection rather than with periodic inspection (Pandey and van der Weide 2009). For the MH-60S example, a non-homogenous Poisson process is the best approximation of failure rates that occur independently of the preceding failure (Pandey and van der Weide 2009). The maintenance data available for the MH-60S shows this principle to be true of component failure in helicopters. Therefore, the equations presented by Pandey and van der Weide may be useful in optimizing the MH-60S maintenance process.

In addition to studies on the economics of CBM, the bulk of the research with close relevance to this investigation is found within engineering literature. These studies provide validation of CBM tools in practice and optimization of their use, including examinations of CBM principles and the IMD/HUMS system used on the MH-60S. One of the most important aspects of a proper CBM regime is how to best implement the necessary monitoring system. Since the goal of CBM is to reduce costs, a useful monitoring system must be reliable and as comprehensive as needed.

Studies by both Bechhoefer and Bernhard (2005) and Wegerich (2004) attempted to determine the proper monitoring system design for military helicopters. Wegerich, working with data obtained from NAVAIR on H-60 gearboxes, developed the notion of construction and comparison on similarity-based models (SBM) for improved diagnostics (Wegerich 2004). Using the SBM models, the normal vibrations of H-60 gearboxes could be isolated, with only abnormal signals remaining and allowing for the detection and tracking of subtle faults (Wegerich 2004).

In addition to Wegerich, a similar study on the AH-64 Apache helicopter by Coats et al. (2011) found that separation of fault signals from normal vibration levels led to

improved fault detection rates. The Coats study provides an improved process for monitoring system development that has led to better fault detection rates in the AH-64 IVHMS-HUMS and similar systems (Coats et al. 2011). Bechhoefer and Bernhard applied a technique to determine a threshold for fault tolerance to the UH-60L helicopter that uses the same IMD/HUMS monitoring system as the MH-60S. In this study, the authors developed a way to create a threshold of vibrations that would minimize false alarm rates and provide a conservative detection capability for faults (Bechhoefer and Bernhard 2005). Finally, in conjunction with this work, Gauthier (2006) found that the introduction of CBM+ into H-60 engine monitoring systems required the minimization of false alarms to produce cost savings when compared to schedule-based maintenance.

The most important lesson to be learned from these studies lies in the effectiveness of legacy health monitoring systems, such as IMD/HUMS, to detect faults before they occur. Well-developed systems exist to provide a robust system fault monitoring capability in helicopter engine and rotor systems, so it is possible to implement a CBM process. A CBM process can meet the needs of both the DOD and Navy CBM programs in terms of safety and reliability, and studies suggest that CBM is less costly in terms of labor and dollars than schedule-based maintenance (Pandey and van der Weide 2009). Conversely, much of the NAMP process is driven by the comfort of users who have achieved success for more than two generations using a standardized, schedule-based process. The current culture of Navy maintenance departments requires a more robust study of the tangible results of CBM tools to understand what can be gained by implementing a more complete CBM process.

D. IMD/HUMS

For any CBM program to be successful there is a need to have a robust monitoring system to gather data and monitor component performance. This monitoring is needed because inspection must be replaced by another action that ensures the effectiveness of aircraft systems. Since the purpose of CBM is to eliminate the need for periodic inspections, any monitoring system must be able to ensure the safe and efficient operation of components achieved under legacy maintenance systems, such as the NAMP for example. The MH-60S uses the Integrated Mechanical Diagnostics Health and Usage System (IMD-HUMS) to monitor components and provide the operator and maintenance team with data related to component performance. To gain a better understanding of IMD-HUMS, the Vibration Analysis Manual Integrated Mechanical Diagnostic System (VIB-200) provides the guidance used by maintenance departments and operators for IMD-HUMS (NAVAIR 2010). The VIB-200 serves as the primary technical publication for IMD-HUMS operation and maintenance in the MH-60S.

1. IMD/HUMS Components

The VIB-200 contains robust descriptions of both the IMD-HUMS system components and operator instructions. Figure 5 provides a basic overview of the system as presented in the VIB-200, including all of the major system components that are discussed in this section.

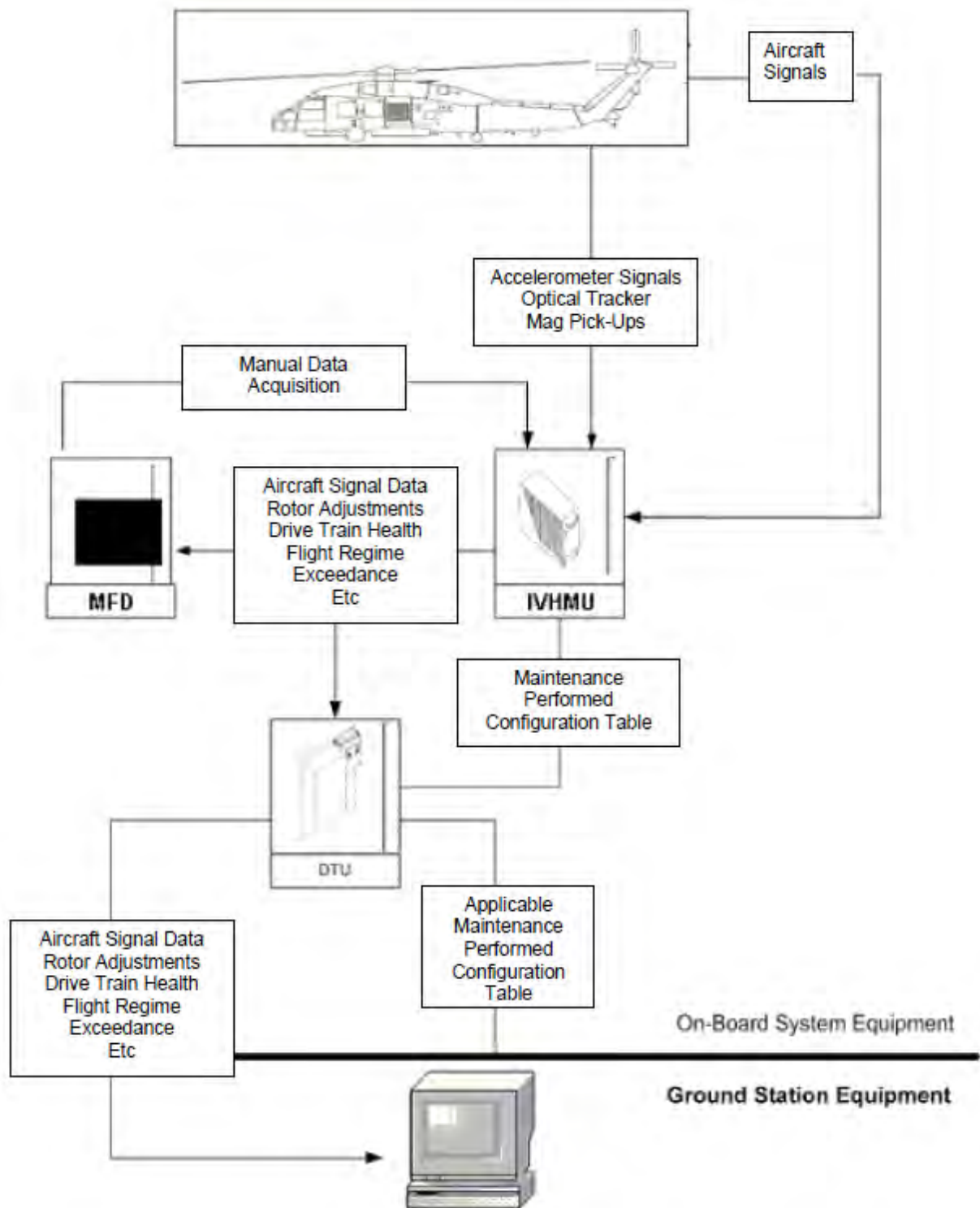


Figure 5. MH-60S IMDS Block Diagram (from NAVAIR 2010, 004 00-8).

Before beginning the discussion of IMD-HUMS components from Figure 5, it must be noted that IMDS and IMD-HUMS refer to the same system and are used interchangeably throughout the VIB-200. IMDS is the MH-60S maintenance nomenclature for the Goodrich IMD-HUMS system, as it is referred in other publications.

The IMDS is divided into two separate major subsystems, the On-board System (OBS) and the Ground Station (GS) (NAVAIR 2010). As the name suggests, the OBS contains all of the systems that monitor the aircraft components and the GS provides data storage and analysis capabilities. The OBS is subdivided into an Integrated Vehicle Health Management Unit (IVHMU), Data Transfer Unit (DTU), and Multifunction Display (MFD) (NAVAIR 2010). The IVHMU serves as the hub for the system, containing a computer that is responsible for monitoring installed accelerometers, magnetic pick-ups, tracker signals and aircraft parameters (NAVAIR 2010). The IVHMU processes all of the data received from the various monitoring components and presents the information to the operator (pilots) through the IMDS section on the MFD. The IVHMU also saves all information on removable Personal Computer Memory Card International Association (PCMCIA) cards through the DTU. These PCMCIA cards are then able to be inserted into a reader at the GS for aircraft data download and analysis (NAVAIR 2010). For the sake of brevity, Table 5 and Figure 6 have been included to provide the OBS sensors and their location on the aircraft. Together, Table 5 and Figure 6 provide a comprehensive description of the systems monitored by IMDS.

Table 5. IMDS Accelerometers (after NAVAIR 2010, 004 00-7).

DTU
IVHMU
Inline Remote Charge Converter (RCC), Cold Accelerometer
Inline Remote Charge Converter (RCC), Hot Accelerometer
Disconnect Coupling Accelerometer
Disconnect Shaft Viscous (Pylon) Bearing Accelerometer
Intermediate Gearbox Input Accelerometer
Intermediate Gearbox Output Accelerometer
Main Gearbox Port Accelerometer
Main Gearbox Port Ring Accelerometer
Main Gearbox Starboard Accelerometer
Main Gearbox Starboard Ring Accelerometer
Main Gearbox Tail Take Off Accelerometer
No.1 Engine Accessory Gearbox Accelerometer
No.1 Engine Aft Accelerometer
No.1 Engine Forward Accelerometer
No.2 Engine Accessory Gearbox Accelerometer
No.2 Engine Aft Accelerometer
No.2 Engine Forward Accelerometer
No.1 Support Bearing Accelerometer
No.2 Support Bearing Accelerometer
No.3 Support Bearing Accelerometer
No.4 Support Bearing Accelerometer
Oil Cooler Axial Accelerometer
Oil Cooler Vertical Accelerometer
Port Driveshaft Input Accelerometer
Starboard Driveshaft Input Accelerometer
Swashplate Vertical Accelerometer
Tail Gearbox Input Accelerometer
Tail Gearbox Output Accelerometer
Rotor Trim and Balance Uniaxial Accelerometer
Rotor Trim and Balance Biaxial Accelerometer
Rotor Trim and Balance Triaxial Accelerometer
4G Vertical Accelerometer
Main Rotor Magnetic Pick-Up
Tail Rotor Magnetic Pick-Up

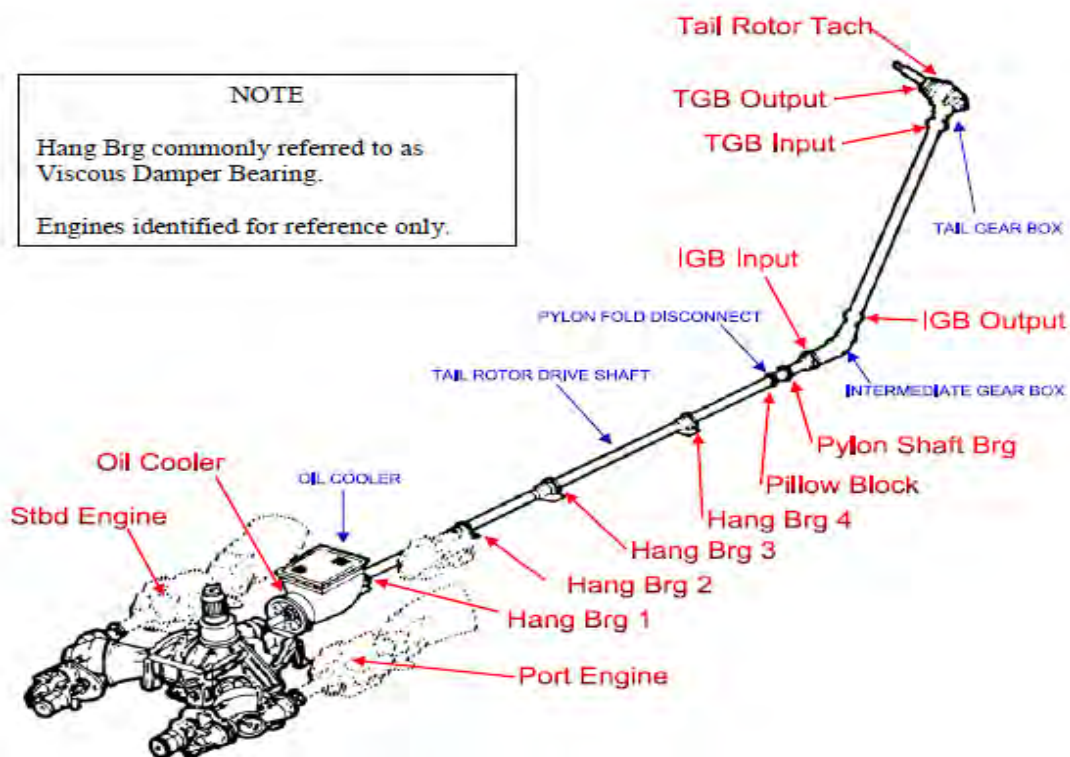


Figure 6. IMDS Accelerometer Diagram (from NAVAIR 2010, Figure 4A).

The information that is collected by IVHMU and stored on PCMCIA cards via the DTU can then be downloaded at the GS for analysis. The GS is compatible with the Windows Operating system and provides the ability to collect and store data for analysis by maintenance personnel on individual aircraft (NAVAIR 2010). Table 6 contains the ground station capabilities for IMDS. The combination of the OBS and the GS provides the capability for the MH-60S to implement CBM. As can be seen in Figure 6 and Table 5, IMDS monitors vibrations from the main rotor and tail rotor along with associated drive shafts. IMDS additionally monitors engine performance and aircraft parameters, and provides a robust feedback to the operator by using of exceedances displayed through the MFD (NAVAIR 2010).

The combination of on-board systems allows the maintenance team to constantly monitor aircraft performance throughout every flight. Monitoring also provides feedback when a monitored system has exceeded operational limits or the aircraft has exceeded

flight parameters. This information is stored in the ground station after each flight and provides a complete record of aircraft system performance. Using this record, maintenance efforts can be tailored to the needs of each individual aircraft and maintenance can be performed as necessary when limits are exceeded. That is to say, maintenance can be provided based on the condition of the aircraft, which constitutes a condition-based maintenance system. The usefulness of the IMDS and its limits will be further addressed as part of the Gap Analysis in Chapter IV.

Table 6. IMDS Ground Station Capabilities (from NAVAIR 2010).

Vibration diagnostic checks	Usage Computation and Tracking
Detect and display of exceedances	Regime Identification and Tracking
Strip Chart analysis	Regime Identification and Processing
Archive mission data	Flight Operations Management
Track engine performance	Fault/BIT Display
DTMU Initialization and Read	Maintenance Management
Operation Exceedance	Pilot Debrief Operations
Rotor Track and Balance	Engine Performance Trending
Strip Charts of Aircraft Data	Display and Trending

2. IMD/HUMS Usage

IMD/HUMS is currently used throughout the HSC community, but to varying degrees depending on the squadron. As of 2014, there are nine HSC squadrons in the HSCWP that fly the MH-60S, and each has IMD/HUMS capability. Currently, the IMDS is not used by any squadron to facilitate CBM. The number of IMDS capable aircraft in the squadron's inventory, IMDS is used only to facilitate FCFs, daily maintenance, and collect data. IMDS usage is described in the MH-60S NATOPS Flight Manual and the VIB-200, which are the major operator directives that currently exist. Needless to say, IMDS usage is limited in its current form. Instead, all maintenance is currently conducted in accordance with NAMP directives and follows the cycles as described in Chapter II.

As discussed in the Boundaries section of this chapter, there are three distinct types of HSC squadrons: Expeditionary, CVW, and FRS. Each type of squadron uses

IMDS but the number of aircraft capable of employing the system varies by squadron. For this research, the data has been collected for HSC-3, HSC-8, and HSC-21. Each squadron uses the IMDS system differently. For instance, HSC-3 is an FRS squadron that has a total of 18 aircraft that have flown and undergone at least one phase cycle in the last year. Of these 18 aircraft, only five were equipped with IMDS capability during the time period of this investigation. At HSC-21, there were 10 aircraft flown, of which only 2 were IMDS capable and none currently attached to the home guard at NAS North Island. On the other hand, HSC-8 has eight aircraft that met the same criteria for flying and phases and seven of these aircraft were IMDS capable during the same time period.

Since IMD/HUMS capability is dispersed throughout the fleet unevenly, simply implementing the system in each aircraft is a major barrier to CBM transition. Aircraft can be retrofitted to include IMDS, and this is routinely accomplished as part of the Depot level maintenance process. That is not to say that IMDS is not useful to the fleet in its current form. Each flight in an IMDS capable aircraft is recorded through the PCMCIA cards and the data is stored through the ground station. Once stored at the ground station, the data is stored on a Citrix server and accessible to local maintenance personnel and the In-Service Support Center at Cherry Point, NC. This data collection effort is in compliance with the NAMP directives discussed in Chapter 2 for the collection, storage and use of data to improve processes. At this time, the data collected has not driven any changes in the structure of H-60 maintenance practices.

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IV. GAP ANALYSIS

One of the most important aspects of the modern DOD acquisitions environment is its focus on capabilities. The JCIDS process makes clear that the focus of DOD acquisitions projects should be to prioritize capabilities and ensure that systems deliver these capabilities (DOD 2012). Therefore, the gap analysis framework that was developed in Chapter III focuses on determining the gaps that exist between current capabilities and desired capabilities. Langford and Franck, as discussed in Chapter III, devised a scheme for evaluating the value of delivering these capabilities. This work serves as the theoretical basis for the gap analysis of the MH-60S that is found in this study.

Previous chapters established the current state of H-60 maintenance, along with the desired capabilities of both the Navy and the DOD. It is clear that at all levels of the military that CBM is a desired capability, but there have been varying levels of CBM implementation to date. The current maintenance cycle for all DON aircraft is outlined in OPNAV 3110.11U, which details the use of the Planned Maintenance Interval (PMI). Each Type/Model/Series (T/M/S) aircraft has a specific PMI cycle depending on the usage of CBM or calendar-based maintenance. An example of a CBM aircraft is the AH-1W/Z helicopter operated by the Marine Corps. The AH-1W/Z “Cobra” uses a CBM cycle and has its PMI is two 36-month cycles with maintenance cued from condition-based needs (Department of the Navy [DON] 2013).

Currently in the MH-60S, there is a fixed 36-month PMI cycle where identical maintenance is conducted on all aircraft due to the lack of CBM capability. Not all MH-60S aircraft possess IMDS, but aircraft are retrofitted with the IMDS system as part of depot-level maintenance. This study includes a total of six aircraft that have been upgraded with the IMDS system during PMI, as review of the aircraft maintenance records show. Due to the necessity of having aircraft available for operational tasking, coupled with the cost of the IMDS system, an immediate IMDS upgrade of the entire fleet is not feasible. For this reason, along with the changing operational and monetary

environment discussed in Chapters I and II, it is reasonable to characterize the lack of CBM capability as an emergent threat to the helicopter community.

A. STUDY SUBJECTS

Perhaps the most pressing question to be answered by any research can be posed as follows: who are we studying and why is the study needed? The answer becomes self-evident after reviewing of the current state of affairs in the DOD. Due to the high cost of acquiring new systems and the reduction in available funding for DOD, it is necessary to find ways to make legacy systems more cost effective. As for the question, who would make a good candidate for a study on the use of Conditional Based Maintenance, the MH-60S was chosen as the platform for study for the following reasons, previously outlined in the first three chapters of this thesis. First, the aircraft has been designed for CBM capability but is not maintained using CBM currently. Second, the MH-60S has multiple variants that use the IMDS and variants that do not. Finally, there is a robust data collection system in place for naval aviation, and these systems allow for vast data collection and storage that allow for comparisons to be made within a gap analysis framework.

Having made the choice of the MH-60S, it is important to understand the dynamics of the HSC community that flies the aircraft. The HSC community is composed of three types of squadrons, CVW, Expeditionary, and FRS. CVW is the aircraft carrier based squadrons that are the descendants of the Helicopter Anti-Submarine (HS) squadrons that have deployed on aircraft carriers since the Vietnam War. Expeditionary squadrons are the descendants of the Helicopter Combat Support (HC) squadrons that have accomplished combat and logistics support since the dawn of naval helicopters. Finally, the FRS is a shore-based squadron that serves as the initial training for all aviators new to the MH-60S. The HSC community provides a diverse cross section of capabilities and mission sets. With the waning of the wars in Iraq and Afghanistan, there has been a shift in focus for the entire community. The HSC community and the MH-60S would greatly benefit from any construct that could reduce operating costs, as the intent of this research was to maximize cost savings.

Within the HSC community, three squadrons were chosen for study based on their composition. All squadrons are a part of the HSC Wing Pacific (HSCWP), so they share maintenance facilities and operate under common directives. Additionally, each squadron has varying operational requirements and deployment models, creating a diversity that is not seen within other helicopter wings. The three squadrons chosen were HSC-3, HSC-8 and HSC-21. All three squadrons are reporting custodians for aircraft and conduct maintenance at the operational level, so they each fall within the boundaries of this investigation.

HSC-3 is the Pacific FRS and provides training to fleet replacement pilots and aircrew prior to their arrival in deploying squadrons. HSC-3 is the largest helicopter squadron in the U.S. Navy and currently flies the MH-60S, HH-60H, and SH-60F. HSC-8 is a CVW squadron that has deployed as part of the CVW-9 on-board CVN74. HSC CVW squadrons deploy as an entire unit and serve the rotary wing needs of the CSG. HSC-21 is an expeditionary squadron that deploys as smaller detachments as part of an ESG or with USNS assets. The manning requirements of each squadron are different, as are the number of aircraft that is assigned to each squadron. For the time period of this study, HSC-3 had conducted at least one phase inspection on 18 different aircraft, with 10 aircraft for HSC-21 and 8 for HSC-8. Each squadron has aircraft equipped with IMDS to facilitate Functional Check Flights (FCF) and others that use the older Automated Track and Balance Set (ATABS) system. ATABS, which is not discussed in great detail in this paper, performs many of the same maintenance functions as the IMDS, but is not integrated into the airframe. The ATABS usage is governed by the A1-H60CA-VIB-100, which contains an extensive description of system operations for operators and maintainers (NAVAIR, *Vibration Analysis Manual Automated Track and Balance Set* 2012).

B. MEASURES AND METRICS

Having established the subject of the study, it is important to outline the metrics that will be used. There is a series of metrics and measures of performance that are relevant to the study. For MH-60S maintenance, there are four measures of performance (MOP): maintenance labor hours, flight hours, time usage, and flight safety. The foundation of these four elements is derived from the discussion of NAMP organization and performance improvement in Chapter II. These four MOPs were used to create a series of eight metrics that allow for the comparison of the baseline and alternative cases that are discussed in Chapter V. The metrics and their associated measures are found in Table 7.

Table 7. Measures and Metrics

Metrics	Associated MOP
Operational Availability (A_O)	System Availability
Percentage of Aircraft Incidents caused by Mechanical Failure	Flight Safety
Percentage of Mechanical Incidents monitored by IMDS	Flight Safety
Percentage of Mechanical Incidents caused by Human Error	Flight Safety
FCF Hours per Flight Hour	Flight Hours Usage
FCF Hours per Phase Inspection	Flight Hours Usage
Scheduled Maintenance Hours Percentage	Maintenance Labor Hours
Unscheduled Maintenance Hour Percentage	Maintenance Labor Hours
Difference of Expected and Actual Labor Hours Used per Phase	Maintenance Labor Hours
Average Phase Labor Hours	Maintenance Labor Hours

1. Measure of Effectiveness and Performance

The four measures listed in the previous section can be separated into measures of effectiveness (MOE) and measures of performance (MOP). The definition of effectiveness shall be that used by Blanchard and Fabrycky (2011), meaning “the ability of a system to the job for which it was intended.” For this study, the measures of effectiveness are the ability of maintenance process to meet the NAMP goals discussed in

Chapter II, along with the NAE goals from Chapter III. For the sake of brevity, these are summarized as the ability to provide greater capability to achieve less cost.

The MOPs are related to and derived from these MOEs as a way to measure the performance of the maintenance system. The definition of MOP used for this study comes from the DAU Glossary (2011) as “distinctly quantifiable performance features”, in this case, hours flown, labor hours, availability, and flight safety. Each of these MOPs is discussed in length in the following sections.

a. Maintenance Labor Hours

Maintenance Labor Hours is an MOP that measures the amount of effort required to accomplish maintenance tasks. The total number of hours to accomplish the tasks related to a phase inspection and associated special inspections serves as the measurement for the amount of resources used for a phase. Labor hours do not include all of the costs associated with a phase, as parts usage also incurs a cost. The usage of parts, however, is outside the scope of this study due to the difficulty in cataloguing all of the parts used to replace defects found during a phase inspection. Therefore, maintenance costs will be measured in terms of labor hours and flight hours.

Maintenance labor hours are recorded for every maintenance task and coded based on the type of maintenance being conducted. These codes are part of the NALCOMIS/OOMA system which is used to keep a complete record of all aircraft by BUNO, which is equivalent to the aircraft serial number. More discussion of maintenance job codes and the methodology used to determine the relevant maintenance for this study is found in Chapter V. The purpose of the maintenance labor hours MOP is to quantify the total number of labor hours to accomplish each phase and maximize the number of flight hours achieved per maintenance labor hour.

b. Flight Hours

Flight hours are a desired outcome of any aircraft maintenance effort, as the purpose of maintenance is to attain and maintain aircraft in a flyable status. Flights that are related to maintenance activities are called Functional Check Flights (FCF), and these

flights are used to accomplish the post-phase vibration analysis required by the MCR-400. A review of the VIB-100 and VIB-200 reveals that certain maintenance activities during a phase inspection lead to required flight checks that are accomplished as part of an FCF. Since an aircraft is cannot be certified “safe for flight” under the NAMP until the FCF is completed, FCF flight hours do not provide operational capability (4790.2B 2013). Therefore, FCF flight hours are used as a measure of performance for maintenance actions. The goal of any maintenance effort should be to minimize the number of FCF flight hours, as this allows for more flight hours to be used for operational tasking. FCF hours account for about five percent of all flight hours flown within the sample population used in this study. Flight Hours and FCF usage results are discussed in Chapter V.

c. Availability

Availability is an important measure of the amount of time an aircraft is able to be used for operational tasking. For this study, which is focused on the effects of phase inspections, availability is a MOP determined by the time between phases and the number of days in phase. The availability MOP is directly related to the operational availability metric which measures it. The definition of operational availability (A_O) for this study is derived from Blanchard and Fabrycky (2011) as:

$$\frac{MTBM}{MTBM + MDT}$$

In which MTBM equals Mean Time Between Maintenance and MDT equals Maintenance Down Time.

MTBM is defined as the number of days any aircraft is available for operational tasking. Therefore, MTBM is the time from the completion of the post-phase FCF until the time an aircraft is inducted into phase. Further, the phase induction date is considered the day after the last flight prior to the beginning of the phase inspection, as is the HSC community practice. This phase induction day occurs at the completion of approximately 175 flight hours, plus any additional hours used prior to phase induction in accordance with NAMPSOP directives. MDT is defined as the number of days from the day

following the last flight prior to phase induction until the completion of the post-phase FCF. During this period, any aircraft undergoing a phase inspection is not available for operational tasking, so it is considered unavailable. Operational Availability as a metric is the percentage of time that an aircraft is available for operational tasking between the induction of an aircraft into one phase (A, B, C or D) and the next subsequent phase. The goal of availability as a MOP is to increase time available between phase inspections and reduce the time spent in a phase inspection.

d. Flight Safety

Flight Safety is the final measure of performance, as maintenance processes are used to guarantee the functionality of aircraft systems to ensure safe operations. Flight safety is quantified in the number of aircraft safety incidents over a given period of time. For this study, aircraft safety incidents are measured as the number of hazard reports (HAZREP) that occurred the period from January 2009 until August 2014. This number of incidents does not include flight accidents (mishaps) that caused serious damage to aircraft or injury to personnel. Navy mishap and HAZREP reports attained through the Web Enabled Safety System (WESS) are privileged for use by flight crews only, and no specifics of any incident can be released due to legal concerns. Since compiling data on mishaps would necessarily include a listing of costs or injury information, these reports were not included in this study to protect the confidentiality of those involved.

HAZREP data, conversely, simply provides aircrews with information on possible hazards to aviation. Any information in these reports is provided voluntarily by aviation squadrons, so data can be used without compromising the privileged nature of the report. The measure of flight safety based on maintenance is the number of mechanically related flight hazards. The performance goal of maintenance is to reduce the number of mechanical hazards and human-caused incidents that compromise flight safety.

2. Metrics

The metrics listed in Table 7 provide the quantitative measure for each MOP with which the metrics are associated. The maintenance labor hours MOP is maximized by a reduction in the number of labor hours to complete a phase inspection. Since the phase

includes a “look” and “fix” portion, all maintenance actions related to inspecting and correcting discrepancies are captured as scheduled labor hours. The metrics for the labor hours MOP are therefore the percentage of scheduled and unscheduled maintenance, average phase labor hours and the ratio of planned to actual phase hours used. These metrics determine the relative breakdown of maintenance labor and the efficiency with which maintenance is conducted. These four metrics are further detailed in Chapter V.

In terms of flight hour usage, the metrics are the ratio of FCF hours to total flight hours and FCF hours per phase inspection. These metrics articulate the amount of waste in terms of flight hours needed to achieve operational availability. Additionally, the FCF hours per phase metric determines the number of flight hours that are lost for operational tasking as a direct result of each phase inspection. Finally, the metrics associated with flight safety determine the frequency of mechanical problems not corrected by maintenance action. These metrics provide an understanding of the relative frequency of mechanical safety hazards, the effects of human error on flight safety, and the ability of IMDS to improve flight safety in comparison to non-IMDS capable aircraft.

3. Value

The use of EVM provides a great tool to assist in the gap analysis of the MH-60S, as it provides an easily traceable value for closing the CBM capability gap. By applying these metrics to the data collected, the relative cost of maintenance under alternative scenarios can be determined for each individual aircraft and phase type. Using the equations provided in Figures 2 and 3, the functional gains and losses due to the performance of maintenance can be captured.

The greatest value is attained by maximizing performances while minimizing investments. The investment is the amount of maintenance labor hours used to achieve the functional performance of operational flight time. Therefore, the performance is quantified by the total number of operational flight hours achieved and total amount of availability of operational aircraft. Increasing flight safety, therefore, increases the worth of performance by minimizing losses due to human error and poor maintenance outcomes. Using the available metrics provides a way to quantify this value in terms of

costs and benefits achieved by closing the capability gaps related to CBM. This value determination in turn allows decision makers the ability to weigh the cost of increasing CBM tools against the value that CBM capability provides.

C. CAPABILITIES-BASED ASSESSMENT

1. JCIDS CBA Guide

The JCIDS *Capabilities Based Assessment Guide* serves as an excellent guide for determining capability gaps with a program. The *CBA Guide* outlines the steps that take place in a formal JCIDS CBA. Even though all of these steps are not conducted as a part of this study, the *CBA Guide* does provide the steps necessary to determine if capability gaps exist. The *CBA Guide* provides the following guidance for programs such as the MH-60S.

When performing a CBA relative to an existing capability solution that may require replacement/recapitalization or evolution to meet future capability requirements, the CBA is starting from a known baseline and making excursions to address potential future capability requirements. In this case the CBA should take no more than 60-90 calendar days to demonstrate that the replacement/recapitalization/evolution is required. The alternatives for the solution will be further considered in the AoA or similar review (DOD 2012, A-B-3).

The MH-60S maintenance system meets this definition very clearly, so the gap analysis uses this as a guide. Additionally, the gap analysis uses the following passage to define the necessary steps and as a concept of operations.

A CBA begins by identifying the mission or military problem to be assessed, the concepts to be examined, the timeframe in which the problem is being assessed, and the scope of the assessment. A CBA determines the relevant concepts, CONOPS, and objectives, and lists the related effects to be achieved. A CBA may also lead to policy development or support and validation of existing policies

There is no strict format for a CONOPS, but it should describe the following areas at a minimum:

- (a) the problem being addressed
- (b) the mission

- (c) the commander's intent
- (d) an operational overview
- (e) the objectives to be achieved
- (f) the roles and responsibilities of tasked organizations (DOD 2012, A-B-1).

2. CBA Concept of Operations

Using the CBA Guide as a basis, the CONOPS for the gap analysis includes the following actions: problem to be assessed, mission, timeline, scope, commander's intent, operational overview, objectives to be achieved, roles and responsibilities of tasked organizations. These areas provide key functional performances, drivers of maintenance approach, rationale for maintenance, and an overall characterization of operational sensitivities. The following sections include the description of each of these areas, followed by descriptions of the data that was collected and analyzed.

a. Problem

Due to decreases in funding following the wars in Iraq and Afghanistan, how can the cost of operating legacy systems be reduced? The problem is maintenance on the MH-60S limits the number of operations that can be flown. Limiting the number of flights decreases operational effectiveness and jeopardizes the mission. For the MH-60S, that problem is expressed in terms of a question: what tools exist to achieve cost savings and what impediments should be expected to implementing cost savings?

b. Solution

The use of condition-based maintenance has been identified by the Navy and DOD as a likely source of cost savings and a preferred maintenance method. CBM tools currently exist, such as IMD-HUMS, but have not been used to replace extant maintenance practices based on inspection cycles. Finally, does IMD-HUMS meet all of the needs to close the capability gap between a CBM-only maintenance process and the current maintenance structure?

c. Goal

The primary goal of gap analysis is to determine the structures of value to aid decision-makers. The intent is to maximize value in the tradeoffs of investment versus functional performance. The problem statement serves to create the perspective from which to construct a means for evaluating alternatives solutions. For a system such as the MH-60S, maintenance requires evolution to meet future needs and changes to make the system relevant to changing missions, uses, and requirements. There must be a baseline for current performance that establishes the measurement of the gap, from which alternative solutions are compared.

Therefore, the goal is to create a baseline for comparison, determine possible alternatives, and then to apply a means of comparing alternatives. Based on the scope and available data, the baseline of performance is the number of labor hours and flight hours used to support phase and special inspections in the MH-60S. Alternatives are limited to systems already in existence, so the only alternative is increased CBM using IMDS for the MH-60S. Finally, the means for comparing alternatives was carried out through the constructs of value and worth of capabilities within the set of analyzed solutions using the equations provided by Langford and Franck.

d. Timeline

The timeline for analysis is based on the available data from the MH-60S community. Due to community maintenance requirements, all labor usage and flight hour data is kept for a period of at least 12 months on local servers in each squadron. Flight data is kept in the Sierra/Hotel Advanced Readiness Program (SHARP) and maintenance data in the NALCOMIS Optimized Organizational Maintenance Activity (OOMA). Therefore, the timeline selected was a 13-month period from July 2013 to August 2014 when all flight data and maintenance labor usage is available for the squadrons being investigated. Outside this timeline, maintenance data is discarded as no longer relevant to current operations and the available data becomes more sporadic.

e. Scope

Within the boundaries established in Chapter III, the scope of the research is narrowed to specific activities that can be measured and compared. All aircraft considered for this research are currently part of the HSC Wing Pacific, and were analyzed by BUNO based on the movement of aircraft within the wing due to operational requirements. Additionally, all maintenance actions considered were performed by the reporting custodian for these aircraft, i.e., squadron personnel within the HSCWP.

As part of the NAMP discussed in Chapter III, the scope of maintenance actions is confined to those related to phase and special inspections. The most common comparisons to be made are the number of labor hours used for scheduled and corrective maintenance, with and without CBM. The comparison of these across the entire timeline discussed in the previous section creates an understanding of the amount of effort directed to both scheduled and corrective maintenance actions. Within this framework, the scope is further narrowed to focus on the actions and hours required to complete phase inspections. Since phase inspections require such extensive maintenance, the result is the use of both maintenance labor hours and flight hours to return the aircraft to operational status (NAVAIR 2010). Since Vibration Analysis is required at the completion of each phase due to the nature of maintenance performed, a functional check flight is required after each phase. Therefore, the cost of a phase is related not just to the labor hours used for maintenance but the flight hours for FCF to return the aircraft to mission capable status.

The scope also extends to the special inspections which often occur in conjunction with phase inspections. All told, the scope of comparisons includes the number of labor hours used for corrective and scheduled maintenance, labor hours used for each phase, flight hours used after each phase for FCF, and the effects on operational availability due to aircraft time in phase. Additionally, using the IMDS ground station, exceedances of flight parameters are noted which necessitate inspections on aircraft components accomplished during phase. Through the use of this IMDS data, it is readily determined whether phase inspections would be warranted based on the performance of the aircraft. More specifically, if the aircraft had no parameter exceedances above non-operable light

limits, there would be no reason to perform a maintenance phase due to aircraft condition. The combination of these factors best measures the NAMP requirements for “performance improvement” presented in Chapter II.

The final scope parameter is related to safety of flight. Since the phase inspection cycle inspects all major aircraft systems, there is a genuine concern that CBM could reduce safety. Through statistics compiled from the Web Enabled Safety System (WESS), it is possible to determine the likely cause of mechanical defects which result in mishap or hazard reports. Since the information in these reports is privileged to the H-60 community, it is impossible to release details of any aviation incident. Therefore, through an anonymous investigation of causes, it is possible to determine if IMDS was installed on incident aircraft. Then comparisons can be made to non-IMDS capable aircraft.

f. Commander’s Intent

The commander’s intent is established through the directives governing condition-based maintenance discussed in Chapter III. The common theme in each of these directives is that CBM is the desired end state for all DOD programs. This theme is reiterated in both the CNO CBM directive and the *Naval Vision 2020*. It is unambiguous that the desired capability is a transition to exclusively condition-based maintenance for all legacy systems. Since the MH-60S was designed with the IMD-HUMS as a CBM facilitator, the commander’s intent is to transition to processes that maximize CBM.

g. Operational Overview

Building on the discussion of scope, the operational overview involves the procedures executed as part of this study. The first step was the selection of operational squadrons for data collection with the boundaries of the study. To obtain an accurate cross section of the HSCWP, one of each type (FRS, Expeditionary, CVW) of squadron was chosen for data analysis. As discussed in Chapter III on IMD-HUMS, these squadrons had various IMDS capabilities for their aircraft.

After choosing HSC-3, HSC-8, and HSC-21, a baseline was created for phase requirements in terms of labor and flight hour usage. This work was done using the

OOMA system to catalogue the type of phases conducted during the timeframe and the number of labor hours recorded as a part of each phase. Since OOMA codes individual work by labor hours and the type of work performed, labor hours can be easily determined for each aircraft during the phase period. To determine phase dates, the aircraft is considered to be inducted into the phase after the completion of the last flight prior to the phase inspection date. Since phases are based on flight hours, this determination is a common practice within the community and provides a consistent estimate for the beginning of a phase.

To obtain phase labor hours, an OOMA records query was conducted for all job codes related to the look and fix portions of each phase (NAVAIR 2013). As noted in the MRC-400, all phases include a “look” portion to inspect aircraft parts and a “fix” portion to repair these parts as necessary. The labor hours collected involve all scheduled maintenance jobs coded for the phase occurring between the phase induction date and completion date. The phase completion date is kept in the OOMA inspection records, along with all special inspection dates.

Once the data was collected for all aircraft in the squadron’s inventory, the IMDS ground station was analyzed. Using the ground station, all IMDS equipped aircraft were checked for exceedances related to monitored systems. Any consistent exceedance beyond the non-operable flight limit was considered a facilitator of phase maintenance. That is to say, if no exceedance was discovered beyond a non-operable flight limit, the phase is considered not warranted for the purposes of this study.

In terms of flight hours, the total number of flight hours for each aircraft was collected for each BUNO in the squadron’s inventory. Additionally, the FCF hours related to each phase were collected. These hours were determined using the SHARP records for each BUNO and related to the date of the FCF. Since community practice requires a FCF to be completed prior to operational tasking, the first flights after each phase completion are FCFs. The VIB-100 and VIB-200 require that post-phase FCF be performed based on the maintenance that is performed during the phase inspection. FCF flight hours performed in conjunction with phase inspections include all flight hours from the phase completion date until the first non-FCF flight. This method of tabulating FCF

hours related to phase maintenance is accurate since the FCF completion allows the aircraft to again execute operational tasking, per community NATOPS directives. SHARP flight records are coded by flight mission type, so FCFs related to phase are easily distinguished in the flight record and the FCF flight hours accurately collected.

To measure the effects on operational availability, the flight record was used to determine the number of calendar days that an aircraft is unavailable for tasking due to phase maintenance. This calculation was completed for each BUNO starting from the day following of the last flight prior to the phase completion date until the date of the FCF completion following the phase. Since this number is reported in days, the aircraft is considered operationally available the day of the last flight prior to phase and after the exact time of the FCF completion. This measure provides an accurate measure for the number of days of operational availability lost directly as a result of phase inspections.

Once all of this data was collected, a series of comparisons was made between the different aircraft populations. Additionally, the value and worth equations from Chapter III were applied to the results to determine the value of closing any capability gaps. These comparisons are discussed, along with the results and conclusions, in Chapters V and VI.

The final operations performed involved the analysis of safety reporting data. This data was collected from the Naval Safety Center WESS system and involved all MH-60S aircraft incident (HAZREP) reports from 2009-2014. Since these reports are privileged (due to the legal implications of aircraft incident information), no specifics from any report are released as part of this analysis. Using the reports, anonymous statistics were created for each aircraft incident, based on whether there was a mechanical cause. If a mechanical cause existed, the aircraft was categorized as IMDS capable or non-IMDS capable. This comparison allows for the determination of any persistent capability gaps in IMDS aircraft that will require further engineering. The results of the flight safety review and comparisons between IMDS and non-IMDS capable aircraft safety records are reported in Chapter V.

h. Objectives

The objectives of the gap analysis are outlined within the CBA Guide. For the MH-60S, one objective is to create an accurate baseline for usage of labor hours and flight hours as a result of conducting a phase. Another objective is to determine the value created by IMDS capability, both under current usage and with the desired CBM capability. For aircraft equipped with IMDS, the objective is to determine if routine operations necessitate phase maintenance as a result of exceeding operational limits. The final objective is related to the ability of IMDS to monitor aircraft safety. Through the use of aircraft incident data, any remaining capability gaps related to the monitoring capability of IMDS are determined and recommended for further engineering. Together, these objectives combine to provide the value of closing the CBM capability gap and identify any residual capability gaps that exist.

i. Roles and Responsibilities

The roles and responsibilities are in many ways external to this study, but relate to the use of its results. Since this study is not a JCIDS product, the roles and responsibilities are filled nearly exclusively by the author. On the other hand, the results could lead to a more formal JCIDS capabilities investigation, which would greatly benefit the HSCWP. The HSCWP serves as the entity responsible for meeting operational tasking using the MH-60S.

As the administrative commander for HSC CVW squadrons and the operational commander for FRS and Expeditionary squadrons, the HSCWP has the responsibility to maximize use of the results of this study. Since the HSCWP has a non-deployable FRS squadron, HSC-3, which is part of this study, many of the recommendations can be applied in a more controlled environment. The conclusions and extensions of this study are discussed in Chapter VI, and the future roles and responsibilities will be conferred in greater detail.

V. RESULTS

Having discussed the parameters of this study in Chapters I-IV, the results are presented and analyzed. This chapter begins with a description the data collection methods that were used. From this data, a baseline of phase maintenance was created for comparison and detailed in this chapter. Next, an alternative for the current phase maintenance processes is proposed and compared to the baseline case. Finally, a discussion of value concludes this chapter, including a consideration of the capability gaps that are closed by the alternative phase process and remaining gaps in CBM capability not addressed by IMDS.

A. DATA COLLECTION METHODS

Data collection was done using the available maintenance data from HSC-3, HSC-8 and HSC-21 for the period from 1 July 2013 until 1 August 2014. These squadrons were described in detail in Chapter IV, and each squadron operates under common maintenance practices within the HSCWP. The major sources of data included both the NALCOMIS/OOMA system, used to report maintenance actions, and the IMDS ground station, which collects IMDS rotor and vibration data. The IMDS ground station includes the mechanical diagnostics tools (MDAT), which provides mechanical data for accelerometer locations throughout the aircraft described in Table 5. Additionally, the use of the Naval Safety Center WESS program is described as the source of flight safety data. The information in this section is a supplement to the Concept of Operations section found in Chapter IV and provides a greater level of detail for the data collection methods from each data source.

1. NALCOMIS/OOMA

NALCOMIS/OOMA is the software database that is used to catalogue all maintenance jobs within HSC squadrons. NALCOMIS/OOMA was discussed in Chapter II of this study and the program is outlined in Chapter 13 of the NAMP (2013). Since all of the squadrons involved in this study are operational level maintenance activities, the Optimized Organizational Maintenance Activity (OOMA) was the interface used to

access maintenance information. OOMA maintains all maintenance, logistics, and flight records for aircraft that are currently in an individual squadron's inventory (COMNAVAIRFORINST 2013). For the purpose of compiling historical maintenance work, all maintenance labor actions, i.e., jobs completed, are required to be stored in OOMA for at least 12 months (COMNAVAIRFORINST 2013). Additionally, this historical data may be available up to five years and catalogued by BUNO (COMNAVAIRFORINST 2013). The use of BUNOs means that when an aircraft is transferred to another squadron, the accepting squadron will have a complete record of aircraft maintenance and logistics information for at least 12 months.

The availability of OOMA data for each squadron in the aircraft sample allows for the collection of maintenance usage data. The data collected from OOMA for this study was focused on maintenance labor hours by BUNO for aircraft within HSC-3, HSC-8 and HSC-21. Not all aircraft in these squadrons were part of the study. Since the focus is the effects of phase maintenance, only aircraft that had undergone a phase within the period from July 2013 to August 2014 were considered. For example, HSC-3 had several aircraft which were in O-level preservation and did not fly enough during the study period to warrant a phase inspection. These aircraft, therefore, were excluded from the sample.

Additionally, aircraft that were on a detachment away from the home station during the time data was compiled were also excluded. Since these aircraft are not located with the "home guard" portion of the squadron, the data is not available through local OOMA database. The combination of this fact along with the fact that most OOMA data is only available for 12-15 months made collection of data for these aircraft during the study period unreliable. Therefore, the data from these deployed aircraft was also excluded.

Using the OOMA records from each squadron, the dates of phases within the study time period were catalogued. The phase window was considered the time from the end of the last flight prior to phase induction until the date of the phase completion. Since OOMA catalogues all maintenance labor hours by type maintenance (TM) code, actions

are logged by the applicable code during both the “look” and “fix” phases (COMNAVAIRFORINST 2013).

“Look” and “fix” mean that any inspection carried out and the actions to correct discrepancies found during said inspection are included as scheduled maintenance under the applicable code. The codes that were considered applicable to each phase were coded as: “Phase Inspection”, “Special Engine Inspection”, “Hourly Special Aircraft Inspections”, “Cycle or Event Special Aircraft Inspection”, and “Daily, Turnaround, Special Inspections and Preservation or Depreservation Actions” (COMNAVAIRFORINST 2013). Using the ad hoc query feature in OOMA for the specified TM codes and phase dates, maintenance labor hours were collected for each phase inspection on each aircraft in the study sample. One caveat to note is the inclusion of special inspections does increase the number of inspection actions if conducted in conjunction with a phase. To include this in the total for each BUNO, all 364, 546 and 728 day inspections that occurred during the phase window were taken into account as part of the expected labor hour calculations. Expected and actual labor hours are covered in more detail later in this chapter.

In addition to phase labor hours, OOMA was also used to compile total maintenance labor hours, along with scheduled and unscheduled labor hours. To acquire the data for the “scheduled maintenance percentage” metric, the total number of labor hours and the number of unscheduled labor hours were collected for each aircraft. These labor hours were collected for the entire time period and provide an understanding of the complete workload for each individual aircraft. All labor hours were compiled by BUNO and used to populate metrics and for statistical analysis purposes discussed later in this chapter.

2. Sierra/Hotel Advanced Readiness Program

The Sierra/Hotel Advanced Readiness Program (SHARP) was used to collect all flight hour data for each of the aircraft in the study. OOMA also maintains flight data records, but HSC community standards specify that flights are logged in SHARP and the data is then transferred to OOMA electronically. This transfer ensures that all flight data

used for operations and maintenance purposes is identical. SHARP was chosen for flight record information due to the ease of use over the OOMA flight record data.

SHARP data was used to calculate flight hours, FCF hours, and availability measures of each BUNO. SHARP is maintained as a local depository of flight hour data in each squadron, and flight hour records are maintained by BUNO for all flights for an indeterminate period. For this reason, all squadrons in the study had data on flight hour available for at least two years, providing more complete records. On the other hand, only flights that took place when the specific BUNO was in the squadron's inventory are maintained in the log, which is not transferred along with the aircraft. For this reason, the flight hour histories of each BUNO were tracked through multiple SHARP databases to form a complete record.

Using the SHARP records, a complete flight history for each BUNO was constructed from the end of the phase inspection previous to the timeline of this study through 1 August 2014. This date range allowed for the calculation of MTBM and MDT for availability purposes, along with the collection of FCF flight hour and total flight hour data. This information was used to calculate the "Operational Availability", "FCF Hours Per Flight Hours" and "FCF Hours Per Phase Inspection" metrics from Table 7.

3. IMDS Ground Station

IMDS ground station data was used to determine trends in component performance that would warrant further inspection. IMDS ground station includes both the ground station (GS) and MDAT databases. The GS was used to collect data on rotor track and balance performance between phases, and MDAT used to collect mechanical diagnostic data on various parts of the aircraft. All IMDS data was collected by BUNO for each IMDS capable aircraft in the sample. Since the purpose of IMDS data is to support the diagnosis of failures before they take place, the relevant time period for each BUNO is limited. Data was collected from the time of post-phase FCF completion until the last flight prior to phase induction for each BUNO. This period represents the time when an aircraft is certified safe-for-flight and trends in performance would warrant further maintenance. Since the current phase process includes the removal and

replacement of IMDS monitored components during a phase inspection, data collected during FCF is used to correct performance shortfalls. Therefore, data from these flights is expected to exceed limits and is not indicative of long-term performance. For this reason, data from post-phase FCF flights was excluded to ensure only operational performance trends were captured as part of each aircraft sample.

This study used the available data for each aircraft during these inter-phase periods at various locations to determine the necessity of certain phase inspections. An aircraft was determined to require additional phase inspections if the IMDS non-operable flight limit was exceeded on multiple consecutive flights. Data collected from the IMDS GS and MDAT was then used to create the alternative phase maintenance case. The data collected was related to trends in component performance and included 1/revolution vibrations for the main rotor, port and starboard engine input modules, tail disconnect coupling, and tail rotor drive shaft. This sampling includes the major components monitored by IMDS as shown in Table 8. The results from the GS and MDAT data and their implications are discussed later in this chapter.

Table 8. IMDS Samples.

Components	System Monitored
Main Rotor	Main Rotor Track and Balance
Port/Starboard ENG Input Module	Engine Output Shaft Performance
Disconnect Coupling	#1-#5 Tail Drive Shaft Vibrations
Tail Rotor Output	Tail Rotor Vibrations

4. Naval Safety Center Web Enabled Safety System

The Naval Safety Center Web Enabled Safety System (WESS) was used to collect data related to flight safety. As was discussed in Chapter IV, this data is privileged, only available to aircrews, and used to improve safety in flight operations. The WESS system was used to collect all HAZREP data for MH-60S aircraft by squadron from January 2009 until August 2014. The specifics of each incident cannot be published, but anonymous statistics were collected to create the “Percentage of Aircraft Incidents caused by Mechanical Failure,” “Percentage of Mechanical Incidents monitored by IMDS,”

“Percentage of Mechanical Incidents caused by Human Error.” Combined, these metrics reveal the number of safety issues related to mechanical problems and the amount that these are driven by human errors. This data helps provide context to the safety of eliminating certain phase inspections. Flight Safety will be discussed as part of the alternative phase inspection later in this chapter.

B. DATA ANALYSIS BASELINE

Using the techniques outlined in the CBA from Chapter IV and the data collection methods from this chapter, a baseline for MH-60S maintenance performance was created. This baseline used the measures of performance and metrics outlined in Chapter IV to describe the current state of the MH-60S maintenance program. Since some aircraft possess IMDS capability and other do not; the baseline assessment must also include analysis of the current value of IMDS. That is to say, does IMDS capability provide any value by itself with implementing CBM? The first task is to determine the current effects of IMDS on the NAMP maintenance process, followed by a construction of a baseline using these effects. The results show that IMDS capability has a minimal positive effect on the current maintenance program. Therefore, a single baseline case was developed for all MH-60S aircraft, regardless of installed IMDS capability.

1. IMDS and Non-IMDS Capability

Since the purpose of this study is to determine the value of implementing a CBM capability into the MH-60S maintenance process, the extant value of CBM tools provides insight that enlightens the utility of CBM capabilities. The aircraft considered for this study includes a sample of 29 aircraft and 73 total phases. These phases are broken into A, B, C, and D by squadron with the data found in Table 9.

Table 9. Phases by Squadron.

Phase Type	HSC-3	HSC-8	HSC-21	Total by Phase
A	13	5	3	21
B	8	6	3	17
C	9	4	3	16
D	11	5	4	20
Total By Squadron	41	20	13	73

From this sample, there were 12 IMDS capable aircraft and 17 non-IMDS capable aircraft. It is impossible to compare IMDS capability's effect on phases within any squadron other than HSC-3. This conundrum arises because HSC-8 completed only four

phases on two aircraft that were non-IMDS capable and HSC-21 had no IMDS capable aircraft in its sample. For this reason, the effects of IMDS capability will only consider the entire sample population. This situation is less than ideal, due to differences in squadron efficiency and labor hour reporting that are evident in comparisons of phase types. Consequently, the lack of IMDS and non-IMDS aircraft within any given squadron would lead to an introduction of bias due to small sample size if these comparisons were made.

To determine if IMDS capability had any positive value, it is necessary to compare the results of IMDS and non-IMDS aircraft in terms of operational availability, post-phase FCF hours and phase labor hours. Since two samples were compared, a t-test assuming equal variances was used with an alpha of 0.05. In all cases, the null hypothesis shall be considered that IMDS capability leads to no difference in mean metric value. The alternative hypothesis is that IMDS capability produces a difference in the mean value of each metric. This relationship is presented in Figure 7.

Figure 7. IMDS Capability Hypothesis Test

$$\begin{aligned}H_0: \mu_{\text{IMDS}} &= \mu_{\text{NON-IMDS}} \\H_1: \mu_{\text{IMDS}} &\neq \mu_{\text{NON-IMDS}} \\ \alpha &= 0.05\end{aligned}$$

a. Maintenance Labor Hours

The first case to be compared is the difference between maintenance labor hour usage with IMDS capability installed or not-installed. Many special inspections are included as part of the phase and these actions are not distinguishable from the labor hour calculations due to the TM codes that are used. Therefore, the most relevant comparison of IMDS efficacy is the mean difference between expected hours for phase completion and actual hours for phase completion. To find this difference, the sum of phase hours to perform the phase inspection in the MRC-400 and any specials (364, 546, 728 days from the MRC-350) conducted during the phase window is used as the expected value of phase inspection hours. The difference between this value and the actual labor hours recorded

for each phase is then subjected to the hypothesis test described in Figure 7. The results of these hypothesis tests are found in Table 10.

Table 10. IMDS Effect on Phase Labor Hours

Phase	A	
	IMDS	Non-IMDS
Mean	164.4	186.3
Variance	153864.88	19531.04
Observations		
P-value (two tail)	0.859	
Phase	B	
	IMDS	Non-IMDS
Mean	64.4	202.6
Variance	10426.64	24271.83
Observations	8	9
P-value (two tail)	0.049989	
Phase	C	
	IMDS	Non-IMDS
Mean	148.41	48.63
Variance	19470.96	19697.7
Observations	5	11
P-value (two tail)	0.2079	
Phase	D	
	IMDS	Non-IMDS
Mean	437.24	464.28
Variance	143300.7	134914.9
Observations	8	12
P-value (two tail)	0.875	
Phase	ALL PHASES	
	IMDS	Non-IMDS
Mean	207.83	231.0
Variance	103626.2	73026.0
Observations	30	44
P-value (two tail)	0.738	

As can be seen in Table 10, there is only one case in which the null hypothesis should be rejected. The “B” Phase shows a statistically significant difference in maintenance labor hour usage between IMDS and non-IMDS aircraft. The results also reveal that the mean of the “C” phase is about 100 labor hours less for non-IMDS aircraft, but this value is not quite significant at the 95 percent confidence level. An

analysis of all data revealed that IMDS does not provide a significant improvement in actual labor hours used in comparison to expected labor hours used at the 95 percent confidence level.

b. Flight Hours

Since the period between MH-60S phase inspections is limited to 175 flight hours by the MRC-400, then value could be achieved by reducing the number of FCF flight hours associated with a phase. Since FCF flight hours are not available for operational tasking, IMDS capability would provide a benefit by reducing the number of post-phase FCF flight hours. Each phase includes different system inspections and repairs, so the comparison of FCF flight hours must be divided by phase type. IMDS capability provides value if “FCF Hours per Phase Inspection” is less than non-IMDS aircraft at the 95 confidence level. The results of the FCF flight hour comparisons are found in Table 11.

As is evident from Table 11, there is a statistically significant difference between IMDS and non-IMDS capable aircraft in terms of FCF hours per phase inspection. For the “B” phase there is a statistically significant difference at the 95 percent confidence level between IMDS and non-IMDS capable aircraft. For the “A” phase, there is a significant difference at the 90 percent confidence interval to reject the null hypothesis, but not the 95 percent confidence level. This fact, combined with the p-value for the “D” phase below 0.25, suggests that FCF efficiency is improved by IMDS. Even though all measures do not meet the 95 percent confidence level, there is still strong evidence to suggest that at least some difference in mean metric values exists. If totaled, the mean expected FCF hours per phase cycle would be 18.3 flight hours for IMDS versus 26.5 hours for non-IMDS capable aircraft. This number is not statistically significant for each phase, but it suggests a non-trivial difference, saving about 1.1 percent of total flight hours per 700 hour phase cycle.

Table 11. FCF Flight Hours t-Test

Phase	A	
	IMDS	Non-IMDS
Mean	3.47	5.88
Variance	1.295	14.91
Observations	9	11
P-value (two tail)	0.0878	
Phase	B	
	IMDS	Non-IMDS
Mean	3.24	7.38
Variance	2.396	9.296
Observations	8	8
P-value (two tail)	0.00413	
Phase	C	
	IMDS	Non-IMDS
Mean	6.14	6.05
Variance	3.173	8.464
Observations	5	11
P-value (two tail)	0.947	
Phase	D	
	IMDS	Non-IMDS
Mean	5.46	7.18
Variance	6.26	10.012
Observations	8	12
P-value (two tail)	0.214	

c. Availability

Availability is measured in terms of the number of days that an aircraft is available or unavailable or operational tasking. In terms of IMDS capability, this measure can be assessed by analyzing the entire sample populations of IMDS and non-IMDS aircraft. The metric “Operational Availability” is used to assess the MOP related to availability. Since operational availability is determined by the time between phases and the amount of time an aircraft is in phase, the type of phase is not important to this measure. The lack of distinction by phase is due to the fact that expected labor hours, i.e., those found in the MRC-400 for each phase, have minimal differences. Additionally, the number of days between phases is not impacted by the type of phase that preceded this time period. Therefore, IMDS and non-IMDS operational availability are assessed

regardless of the phase type. Table 12 contains the results of the operational availability comparison between IMDS and non-IMDS aircraft.

Table 12. Operational Availability (IMDS v. non-IMDS).

	Operational Availability	
	IMDS	Non-IMDS
Mean	0.725	0.659
Variance	0.0315	0.0278
Observations	29	39
P-value (two tail)	0.119	

The results reveal that there is not a statistically significant difference in means at the 95 percent confidence level. The p-value of 0.119 does reveal that the difference in means is not trivial. The p-value does not, however, meet the criteria to reject the null hypothesis, so it must be accepted that the mean operational availability is the same between IMDS and non-IMDS aircraft.

2. Maintenance Performance Baseline

The results of the comparison of IMDS and non-IMDS aircraft reveal that there is a non-trivial difference between their performances. On the other hand, there is not a statistically significant difference in performance at the 95 percent confidence level for most metrics based on availability, flight hours or labor hours. For this reason, the baseline of current performance does not differentiate between IMDS and non-IMDS capable aircraft. The baseline case was created to satisfy the JCIDS CBA discussed in Chapter IV. The baseline forms the heart of the capability gap analysis and was used to measure the value of a CBM alternative.

The baseline case was calculated using the average value of the MOPs and associated metrics from Chapter IV. Three of the four MOPs, maintenance labor hours, availability, and flight hours are included in the baseline case. Flight safety was not used as a part of the baseline. This omission is due to the small sample size of mechanical incidents in the safety data and is discussed in a separate section in this chapter. Baseline cases were formed for both the entire aircraft sample population and the samples of

individual squadrons. These sampling decisions were due to the differing composition of the aircraft variants in each squadron and the different efficiency achieved by the associated maintenance departments. Tables 13-17 contain the performance baseline in terms of maintenance labor usage, flight hour usage, and availability under the current NAMP process.

Table 13. Maintenance Labor Hours Performance Baseline (Part A)

Phase Type	Actual Phase Labor Hours	Expected Phase Labor Hours	Actual-Expected Labor Hour Difference	Percent Over Expected Labor
HSC-3 A AVG	419.2	243.9	175.3	73.17
HSC-3 B AVG	362.5	208.4	154.1	74.40
HSC-3 C AVG	402.9	246.1	156.8	62.02
HSC-3 D AVG	911.1	330.8	580.3	171.36
HSC-3 AVG Phase	536.6	260.8	275.8	105.75
HSC-3 Total Cycle	2095.8	1029.2	1066.5	103.63
HSC-8 A AVG	471.4	251.9	219.5	48.27
HSC-8 B AVG	296.9	223.7	73.2	24.10
HSC-8 C AVG	186.7	239.5	-52.8	-16.10
HSC-8 D AVG	554.8	355.3	199.5	64.93
HSC-8 AVG Phase	382.4	267.8	114.6	33.05
HSC-8 Total Cycle	1509.8	1070.3	439.5	41.06
HSC-21 A AVG	438.0	233.8	204.2	87.35
HSC-21 B AVG	465.2	212.0	253.2	121.83
HSC-21 C AVG	230.0	233.8	-3.8	-1.64
HSC-21 D AVG	709.1	319.2	389.9	122.13
HSC-21 AVG Phase	479.7	255.0	224.6	88.08
HSC-21 Total Cycle	1842.2	998.8	843.5	84.45
A AVG	420.4	243.5	176.9	69.27
B AVG	352.2	214.6	137.6	65.02
C AVG	323.3	245.2	78.1	30.56
D AVG	786.3	332.8	453.5	134.91
All AVG Phase	482.6	261.4	221.3	77.66
All Total Cycle	1882.2	1036.2	846.0	81.65

Table 14. Maintenance Labor Hours Performance Baseline (Part B)

	Scheduled Labor Hours	Unscheduled Labor Hours	Total Labor Hours	Scheduled Labor Percentage
HSC-3 Total	76559.7	38172.9	114732.6	
HSC-3 Average	5104.0	2544.9	7648.8	66.73%
HSC-8 Total	28821.1	17443.8	46264.9	
HSC-8 Average	3202.3	1938.2	5140.5	62.30%
HSC-21 Total	22284.7	15269.6	37554.3	
HSC-21 Average	4456.94	3053.92	7510.86	59.34%
All Total	363403.4	191640.0	555043.5	
All Average	4402.3	2444.4	6846.6	64.30%

Table 15. Flight Hours Performance Baseline (Part A)

	Total FCF Hours	Total Flight Hours	FCF/Flight Hours
HSC-3 Total	374.4	7231.1	
HSC-3 Average	25.0	482.1	5.18%
HSC-8 Total	117.7	2584.4	
HSC-8 Average	13.1	287.2	4.55%
HSC-21 Total	130.8	1960.2	
HSC-21 Average	26.16	392.04	6.67%
All Total	1780.1	33751.8	
All Average	21.5	406.1	5.29%

Table 16. Flight Hours Performance Baseline (Part B)

Phase Type	Phase FCF Hours	Percentage of Flight Hours Lost
HSC-3 A AVG	4.8	2.75
HSC-3 B AVG	6.9	3.92
HSC-3 C AVG	6.1	3.46
HSC-3 D AVG	6.2	3.52
HSC-3 AVG Phase	5.9	3.31
HSC-3 Total Cycle	23.9	3.41
HSC-8 A AVG	2.8	1.57
HSC-8 B AVG	3.5	2.02
HSC-8 C AVG	7.5	4.27
HSC-8 D AVG	7.8	4.44
HSC-8 AVG Phase	4.9	2.78
HSC-8 Total Cycle	21.5	3.08
HSC-21 A AVG	7.8	4.46
HSC-21 B AVG	5.4	3.09
HSC-21 C AVG	4.0	2.30
HSC-21 D AVG	7.1	4.07
HSC-21 AVG Phase	6.2	3.56
HSC-21 Total Cycle	24.4	3.48
A AVG	4.8	2.74
B AVG	5.3	3.03
C AVG	6.1	3.47
D AVG	6.5	3.71
All AVG Phase	5.7	3.24
All Total Cycle	22.7	3.24

Table 17. Availability Performance Baseline

Squadron	MTBM (Days)	MDT (Days)	Ao
HSC-3	63	42	0.602
HSC-8	123	48	0.721
HSC-21	84	24	0.775
All Squadrons	89	40	0.690

The collection of information in Tables 13-17 provides the baseline case for each individual squadron and the entire sample population in terms of the relevant MOPs. This data presents the current state of phase maintenance as applied to the HSC community operating the MH-60S. From this data, all of the metrics from Table 7 are applied to the data collected from each squadron. Additionally, an average of inter-squadron performance is presented. This information was used as the basis for comparison with the alternative phase construction presented later in this chapter.

From this data, one observes that each squadron achieves different levels of efficiency in terms of labor hours, flight hours and availability. In terms of labor hours, the squadrons using more non-IMDS aircraft tend to require more labor. An analysis of the relevant BUNOs reveals that aircraft in HSC-21 and HSC-3 are generally older (lower BUNO), which is the likely cause of the higher labor hour totals. HSC-8, which has mostly IMDS aircraft, has a lower average FCF hour total than the other squadrons, which is expected given the comparisons of IMDS and non-IMDS aircraft made in the previous section. Finally, HSC-3 has the lowest operational availability, but this seems to be a result of shorter MTBM than other squadrons. HSC-21 achieves the best Ao, mostly due to the fact that MDT is about half that of other squadrons. All data collected as part of this study is contained in Appendix A.

C. PHASE INSPECTION ALTERNATIVE

With the baseline data established, it is necessary to create an alternative case for comparison to complete the capability gap analysis. To determine the alternative case, the IMDS ground station data was used to determine the necessity of all actions that take place during a phase inspection. Once the IMDS data was reviewed, an alternative phase structure was proposed. Using this phase structure proposal, metrics from the baseline case that were related to labor hours and flight hours were applied to make a reasonable estimation of the effort to complete phases under the alternative case. Next, availability due to phase maintenance was determined using the results of the labor hour estimates. Finally, the flight safety record was reviewed and results applied to determine the possible safety implications of using the alternative case.

1. IMDS Data

A review of the IMDS ground station data was conducted to determine the ability of IMDS to identify system faults and determine the need to inspect systems monitored by IMDS. As discussed earlier in the IMDS Ground Station section, IMDS data was compiled from several components throughout the aircraft. This data can be found in Appendix B, listed by BUNO number and component. The following components were chosen for review, as they provide an accurate cross-section of all IMDS monitored systems: main rotor, tail rotor, disconnect coupling (tail drive shafts), and input modules (engine output shafts).

As discussed in the IMD-HUMS section of Chapter III, any time an aircraft is operated with IMDS, events are automatically recorded and stored in the DTU. This information is then passed to GS through the PCMCIA cards and catalogued for trend analysis. Using this trend data, it is possible to view the performance between phase inspections to determine the performance of aircraft components and predict possible failures. Trend data was available for all IMDS aircraft during the timeframe of this study, although some specific data points were not available. For each aircraft, all MDAT data (excluding main rotor) was analyzed to determine the highest recorded value, mean, standard deviation, and trend.

Main Rotor data was located in the ground station, with the average value between phases and maximum reading for an individual flight recorded. All data was compared to the non-operable flight limit for the component and RPM from the VIB-200 (NAVAIR 2010). These limits represent a reasonable threshold for maintenance action as by definition, they are below the level where early deterioration of the component will occur (NAVAIR 2010). These limits can be found in Appendix B as part the monitored systems data record. An aircraft component was determined to require all phase inspections related to that component if there was a consistent exceedance of the non-operable flight limit. A consistent exceedance is defined as a recorded limit exceedance on multiple consecutive days or an increasing trend approaching the limit over a longer time span.

Only aircraft from HSC-3 and HSC-8 were IMDS capable, and the results showed very few trends exceeding the applicable limits. For HSC-3, five aircraft were analyzed over the course of 14 phase inspections, totaling 74 components. Within this group, a total of nine systems exceeded the non-operable flight limit at any time. Of this smaller group, only one exceedance was consistently observed and would require additional inspection during phase. HSC-8 had data available for a total of six aircraft, 14 phases, and 82 components. From this group, eight systems exceeded the limits at any time, with only four systems meeting the criteria for additional inspection.

The small number of systems requiring further inspection and the lack of any aircraft requiring inspection of multiple monitored systems concurrently greatly reduced the need for inspection of IMDS monitored systems. For this reason, the alternative case recommends the elimination of phase inspections on IMDS monitored components without clear need in the data trend record. The alternative case eliminates these inspections from the phase cycle and implements a much greater CBM capability.

2. Alternative Phase Inspections

After reviewing the IMDS ground station data, it is clear that IMDS provides the ability to implement CBM under its current usage. This CBM implementation does not mean that all parts of the phase inspections can be eliminated, as the phases still contains

necessary inspections and servicing that IMDS is not currently capable of replacing. For the alternative case, all inspections related to IMDS monitored systems were removed, leaving behind a residual inspection to be conducted on non-monitored systems. This alternative phase should still occur at 175 flight hour intervals, but should include only the inspections found in Table 18. The alternative Phase found in Table 18 includes all inspections to be conducted on each phase, with the ability to include additional inspections as IMDS trends require.

Table 18. Alternative Phase Inspections.

Phase	Maintenanace	Hours	Assist Hours
All		35.8	32
	Hydraulic System Sampling	1.3	1
	Utility Hydraulic System Sampling	1.3	1
	Access Panels Removal and Inspection	8.7	7.7
	Airframe Inspections (Cabin, Transition Section, Tail Cone, Main Rotor Pylon, Tail Pylon)	17	17
	Tail Landing Gear Shock Strut	1	1
	Rotor Brake	0.5	0
	Fuel System	0.5	0.5
	Main Gear Box Radiator	0.5	0
	Auxiliary Power Unit	0.6	0.1
	Fire Extinguishing System	0.7	0.5
	Rescue Hoist and Cargo Hook	0.7	0.7
	Stabilator	2	2
	FLIR	1	0.5
AC		17.4	16.5
	Windshield and Wipers	0.6	0
	Airframe Inspections (Cockpit, Cabin and Tail Cone/Pylon)	6	6
	Torque Shaft Bearing Supports	0.8	0
	Main Landing Gear	5	5.5
	Tail Landing Gear	2.5	2.5
	IGB/TGB Oil Change	2	2
	Data Bus System	0.5	0.5
BD		2.7	1
	Tail Landing Gear Structure	0.7	0
	Environmental Control System	1	0
	Pitot Static System	1	1
A			
	No Additional Inspections		
B		0.7	
	Main Gear Box Radiator	0.7	0
C			
	No Additional Inspections		
D		5	3.5
	Environmental Control System	1.5	0
	Main Landing Gear	1.5	1.5
	Tail Landing Gear Shock Strut	1	1
	Main Rotor Damper System Drain	1	1
	Phase	Hours	
	A	105.4	
	B	72.2	
	C	101.7	
	D	80	

The total expected labor hours for each phase can be seen in Table 18, and there is a significant reduction in inspection hours from Table 2. Additionally, the elimination of inspections on IMDS monitored components eliminates the need for post-phase vibration analysis. The current post-phase vibration analysis is mandated by the VIB-100 and VIB-200 after the completion of certain maintenance actions. These actions requiring vibration analysis have been eliminated from the phase inspection, therefore no vibration analysis, or FCF, is required. Post phase FCF would only be required due to a 30-day no-fly period, the chances of which would be greatly reduced under this alternative maintenance scheme. The following section on Earned Value presents a detailed comparison of the baseline and alternative phase schemes.

D. EARNED VALUE

As Langford and Franck noted, the goal of EVM is to “suggest how management can obtain the best-value solution for the taxpayer’s money” (Langford and Franck 2009, 4). Through the course of the gap analysis, a clear CBM capability gap was identified in the MH-60S. This gap was related to the failure of the maintenance process to maximize the use of CBM tools. As was discussed as part of the CBA baseline, IMDS provides minimal capability in its current usage. In order to maximize the value of IMDS, a new maintenance process must be implemented. An alternative process was conceived using the IMDS ground station data to tailor the current phase process and reduce cost in terms of labor and flight hours. The question remains, however, what is the value of implementing the alternative phase model? To answer this question, the work of Langford and Franck, discussed in Chapter III, was applied to the baseline and alternative cases to find the value of closing the CBM capability gap.

1. Assumptions and Methods

The data found in Tables 13-17 provides a great deal of insight into the assumptions that can be made about maintenance labor usage. Since the baseline phase model includes a “look” and “fix” phase, actual labor hour usage varies greatly for each phase. Since no phase takes the exact amount of time listed in Table 2, it is unreasonable to assume that alternative case labor hours should be taken at face value. The expected hours must be adjusted to reflect the reality of maintenance, and the metric “Actual-Expected Labor Hours Difference” from Table 13 provides the basis for such an adjustment. Using the average of this metric for each phase type, by squadron, a realistic adjustment of expected phase labor hours can be made.

Adjusting the alternative case using the “Actual-Expected Labor Hours Difference” metric allows maintenance actions that correct discrepancies found during a phase to be captured. Even though there is not an exact linear relationship between phase labor hours and each inspection, this method provides an accurate measure from the available data. It is impossible to predict without monitoring capability which systems

will require repair during a phase, so an estimate must be made for the repairs that will take place.

Other assumptions that are made concern the MDT and FCF flight hour usage under the alternate model. Since maintenance requiring FCF is eliminated from the phase inspections, post-phase FCF hours are assumed to be eliminated. Review of the IMDS ground station data substantiates this assumption, as only five systems out of 156 warranted additional inspection during the study timeframe. Since adjustments are made to these IMDS monitored systems during FCF, these figures would likely rise under a CBM alternative. Conversely, no aircraft required multiple additional inspections, so any inspections that lead to FCF in the future are likely to be greatly reduced in number. FCF hours would not be eliminated, but the variable nature of the FCF under the alternate model along with the greatly reduced frequency implies that FCFs should be omitted from these calculations.

MDT must be adjusted as well as FCF hours based on the labor requirements under the alternate model. For this study, labor hours available for phase were 30 per day for all calculations of MDT. The 30 labor hours figure is similar to the efficiency achieved in conjunction with phases with the collected data lasting less than 21 days, which the alternative model is very likely to achieve. In addition MDT was calculated from the completion of the last flight prior to phase induction until phase completion, excluding post-phase FCF. This change is justified for the same reasons as the elimination of post-phase FCF calculations. All aircraft were considered ready for operational tasking on the date of the completion of all projected phase labor hours under the alternate model.

These assumptions were applied to each squadron to determine the value of conversion to CBM between the baseline and alternate models. The final assumption was that all aircraft will be IMDS equipped in the alternate case. This assumption is necessary because IMDS allows CBM capability. If IMDS is not installed, there can be no CBM capability, and thus no difference from the baseline case.

2. Earned Value Calculations

Applying the earned value calculations from Langford and Franck from Chapter III, it is possible to determine the value of closing the CBM capability gap. The equation from Figure 2 is:

$$V_F(t) = \frac{\sum P(t)}{I(t)}$$

The value of the function $F(t)$ is the value of closing the capability gap. $I(t)$ represents investment, labor hours in this case, used to produce performance in functional terms. The functional performance in this case is flight hours, which is fixed at 175 per phase less the number of post-phase FCF hours. Therefore, the value of closing the gap is the difference in operational flight hours per maintenance labor hour between the baseline and alternative models.

Table 19 presents the value calculations for the baseline and alternate models. The calculations in Table 19 reveal that under the baseline case, the value of each phase maintenance labor hour is between 0.185 and 0.897 flight hours, with an average of 0.351 across all squadrons and phases. In the alternative case, the value of one phase maintenance labor hour is between 0.806 and 2.051 flight hours, with an average of 1.097 flight hours per labor hour for all phases across all squadrons.

Langford and Franck also propose the use of quality to determine the worth in gap analysis. This equation is included in Figure 3, and provides that differences in quality can lead to differences in the worth of a capability to a squadron. Safety would be the best measure of quality available, as fewer operational system failures would lead to an increase in the quality of performance. Due to the fact that CBM is not currently used on the MH-60S, there is no data available that provides the rate of component failures under a CBM regime. For this reason, the safety of flight data is much more useful as an indicator of component quality and not maintenance process quality, except in the cases of human maintenance error. Put another way, there is not any data on safety under a

CBM regime, so any alternative scenario that attempts to capture the quality of safety is conjecture at best.

Table 19. Value Calculations.

Phase Type	Baseline Phase Labor Hours	Baseline Operational Hours	Baseline Value	Alternate Phase Labor Hours	Alternate Operational Hours	Alternate Value
HSC-3 A AVG	419.2	170.2	0.406	182.5	175.0	0.959
HSC-3 B AVG	362.5	168.1	0.464	125.9	175.0	1.390
HSC-3 C AVG	402.9	168.9	0.419	164.8	175.0	1.062
HSC-3 D AVG	911.1	168.8	0.185	217.1	175.0	0.806
HSC-3 AVG Phase	536.6	169.1	0.315	172.6	175.0	1.014
HSC-3 Total Cycle	2095.8	676.1	0.323	690.3	700.0	1.014
HSC-8 A AVG	471.4	172.3	0.365	156.3	175.0	1.120
HSC-8 B AVG	296.9	171.5	0.578	89.6	175.0	1.953
HSC-8 C AVG	186.7	167.5	0.897	85.3	175.0	2.051
HSC-8 D AVG	554.8	167.2	0.301	131.9	175.0	1.326
HSC-8 AVG Phase	382.4	170.1	0.445	119.5	175.0	1.464
HSC-8 Total Cycle	1509.8	678.5	0.449	506.8	700.0	1.381
HSC-21 A AVG	438.0	167.2	0.382	197.5	175.0	0.886
HSC-21 B AVG	465.2	169.6	0.365	160.2	175.0	1.093
HSC-21 C AVG	230.0	171.0	0.743	100.0	175.0	1.749
HSC-21 D AVG	709.1	167.9	0.237	177.7	175.0	0.985
HSC-21 AVG Phase	479.7	168.8	0.352	168.9	175.0	1.036
HSC-21 Total Cycle	1842.2	675.6	0.367	662.7	700.0	1.056
A AVG	420.4	170.2	0.405	178.4	175.0	0.981
B AVG	352.2	169.7	0.482	119.1	175.0	1.469
C AVG	323.3	168.9	0.522	132.8	175.0	1.318
D AVG	786.3	168.5	0.214	187.9	175.0	0.931
All AVG Phase	482.6	169.3	0.351	159.6	175.0	1.097
All Total Cycle	1882.2	677.3	0.360	652.7	700.0	1.073

The comparison of value under the baseline and alternative case provides that there is a significant value to closing the CBM capability gap. It is also important to investigate the savings for each squadron in absolute terms. Tables 20 and 21 provide the total savings in terms of labor hours, flight hours, and availability under the alternate model in comparison to the baseline model.

Table 20. Operational Availability (Baseline versus Alternate)

Squadron	MTBM	Baseline MDT	Alternate MDT	Baseline Ao	Alternate Ao
HSC-3	63	42	6	0.602	0.914
HSC-8	123	48	4	0.721	0.968
HSC-21	84	24	6	0.775	0.933
All Squadrons	89	40	6	0.690	0.937

Table 21. Total Labor Hours and Flight Hours (Baseline versus Alternate)

Phase Type	Alternate Labor Hours	Baseline Labor Hours	Total Phases	Total Difference (Labor Hours)	Alternate FCF Hours Saved
HSC-3 A	176.1	419.2	13	3160.7	57.8
HSC-3 B	125.9	362.5	8	1892.5	54.9
HSC-3 C	164.8	402.9	9	2143.3	54.5
HSC-3 D	217.1	911.1	11	7634.4	67.7
HSC-3 Total	683.9	2095.8	41	14830.9	234.9
HSC-8 A	150.8	471.4	5	1602.9	14.7
HSC-8 B	89.6	296.9	6	1243.7	19.2
HSC-8 C	85.3	186.7	4	405.5	30.6
HSC-8 D	131.9	554.8	5	2114.4	33.7
HSC-8 Total	457.7	1509.8	20	5366.5	98.2
HSC-21 A	190.5	438.0	3	742.5	23.4
HSC-21 B	160.2	465.2	3	915.0	10.8
HSC-21 C	100.0	230.0	3	389.8	12.1
HSC-21 D	177.7	709.1	4	2125.4	28.5
HSC-21 Total	628.4	1842.2	13	4172.7	74.8
All A	172.1	420.4	20	4965.4	95.9
All B	119.1	352.2	16	3729.0	84.9
All C	132.8	323.3	16	3048.8	97.2
All D	187.9	786.3	20	11966.8	129.9
All Total	612.0	1882.2	72	23710.0	407.9

3. Flight Safety

Analysis of the flight safety data reveals very little in terms of a comparison between the baseline and alternative models for aircraft maintenance presented in this study. The sample of HAZREP statistics available since 2009 includes a total of 487 flight incidents in the MH-60S. Of these 487 incidents, only 40 had a direct mechanical cause, which in this case means failure of a system or component monitored by IMDS. These 40 incidents included only 16 aircraft that had IMDS installed, so the sample of IMDS monitored incidents is very small. By comparison, only 40 percent of all aircraft reporting a mechanical failure had IMDS to 60 percent without IMDS, but IMDS is typically installed on newer aircraft. One statistic of note is that 25 of the 40 mechanical incidents were related to human maintenance error. This means that about 62.5 percent of all MH-60S HAZREPs are caused by a failure of maintenance personnel.

The three metrics discussed in relation to flight safety are: ratio of mechanical failure to total incidents, percentage of mechanical failure with IMDS installed, and percentage of incidents involving human error. Since the mechanical failure ratio is 8.2 percent of all incidents over five years, aircraft components have a very low failure rate. Additionally, since the human failure rate of this subset of incidents is 62.5 percent, only 15 incidents in four years are related to mechanical failure alone. This statistic suggests that there is no significant increase in risk to aircraft of converting to CBM, due to the low failure rate of components.

IMDS in conjunction with CBM replaces inspections and provides a constant monitoring capability. This monitoring capability coupled with the lower rate of mechanical failures on IMDS aircraft than non-IMDS aircraft suggests that safety would not be compromised in any meaningful way by converting to a CBM process. Conversely, the lower number of inspections might actually increase safety by reducing the largest cause of mechanical failures, human maintenance error.

E. RESIDUAL CAPABILITY GAPS

In Chapter I, there were four major research questions that were posed. Questions 3 and 4 are directly related to the presence of a residual capability gap. Those questions are:

- To what extent is there a gap between current capabilities and the requirement to meet the Navy's stated goal of maximizing the use of CBM at the organizational level?
- Are there any possible solutions that may have been overlooked that could be more effective than the maintenance processes currently in use or development?

The former question above seeks to determine how much the gap analysis succeeded in closing the CBM capability gap. If IMDS is used to the maximum extent possible, the answer to this question is yes, CBM has been maximized in the MH-60S. On the other hand, the answer to the second question is yes, there are solutions that have been overlooked. By the nature of the NAMP discussed in Chapter II, there is no serious consideration of a NAMP alternative besides CBM. For this reason, CBM tools are the only ones currently available for consideration in constructing alternatives. On the other hand, CBM is by no means perfect and there is a large space to explore involving alternatives to the NAMP that fall outside of the CBM structure.

The structure of the alternate phase model reveals CBM cannot replace all of the inspections that are conducted during a phase using IMDS in its current state. This does not necessarily represent a gap in capability that has a value to close. Review of the residual phase inspections under the alternate model shows that many of the inspections likely should not be replaced with CBM. For example, a CBM capability to monitor hydraulic system fluid is not likely worth the expense when sampling is effective and less expensive. It must also be recognized that a non-CBM alternative, such as development of new aircraft systems which require less servicing could also close this residual gap. In the MH-60S, for example, a fly-by-wire control capability could lessen the need for complex hydraulic systems. In turn, this would reduce the need for many of the current maintenance inspections without the use of CBM.

One of the primary ways to further increase the value of CBM would be to lessen the frequency of some inspections common to all phases. For instance, 67.8 hours of inspection are common to all phases even under the alternate model. Inspections of components such as the stabilator or landing gear could be lessened in frequency without an event-based need. That is to say, without exceeding landing limits or a stabilator malfunction, these systems are unlikely to require inspection every 175 flight hours. Additionally, the shortened phases could be combined into larger inspections at greater intervals to further reduce the frequency of inspection and maintenance down time.

The greatest capability gap that stills exists after CBM implementation is a gap identified under the current maintenance process, i.e., the lack of catastrophic failure prediction. There is currently no system on the MH-60S that monitors the physical condition of components. Mishap data, although not revealed in this study, does include incidents of catastrophic component failure with little or no warning to operators. These incidents of physical component failure have not been predicted by IMDS or detected through the inspection process.

The MH-60S tail rotor is especially vulnerable to physical stresses, and a capability of monitoring the physical condition of tail rotor components would improve safety but is outside the realm of CBM. Engine power output is also not monitored by IMDS on a consistent basis. Currently, power checks are completed prior to flight comparing torque and turbine gas temperature to track engine performance. These health indicator tests from the NATOPS flight manual are conducted at a single fixed power setting which is often well below the operating parameters used in flight. Development of more robust engine monitoring could provide a greater CBM capability for diagnosing impending engine failures.

These ideas and other future extensions should be considered, but are outside the scope of this study. In the end, the capability to maintain aircraft available for operational tasking is met by the current NAMP process and CBM alternative. In terms of meeting the functional requirements of “to maintain,” CBM provides a more valuable capability than the current NAMP. Further, there is no residual CBM capability gap under the alternative case per se, but there are areas for even greater CBM usage not presented in this study.

VI. CONCLUSIONS

Analysis of the results from Chapter V reveals that there is a definite value to implementing CBM in the MH-60S. Statistical analysis of aircraft performance with IMDS installed to aircraft without IMDS installed revealed that MOPs were equal at the 95 percent confidence level. As the maintenance program of the MH-60S is currently structured, all aircraft are maintained under the same process regardless of IMDS capability. There is a small, statistically significant benefit to the current use of IMDS in the MH-60S. This benefit is based mostly on the efficiency achieved while conducting the post-phase vibration analysis and FCFs.

The results of this study revealed that in order to achieve a much greater benefit from the use of the IMDS system, it is necessary to implement a more robust CBM regime. The most significant part of any CBM program would be to minimize the amount of phase maintenance inspections on IMDS monitored components in the MH-60S. To determine the structure of an alternative CBM process, a capability gap analysis was used in accordance with the JCIDS *Capabilities Based Assessment Guide* in Chapter IV. This capability gap analysis was then used to determine the value earned by implementing a CBM alternative to the extant NAMP process.

The final results of the gap analysis determined that a CBM capability gap does exist between the Navy's desired aircraft maintenance process and the extant NAMP process. Through the use of data collected at the operational level from the MH-60S, the value of closing this gap was determined for a sample of aircraft within the HSCWP. Use of IMDS ground station data validated the ability of IMDS to monitor components and determine when additional maintenance actions were required for these components. This IMDS ability enabled the elimination of most phase inspections unless a specific component need was identified by IMDS.

Through using data collected from a sampling of MH-60S aircraft within the HSCWP, a baseline of current maintenance process performance was created. This baseline assessed measures of maintenance performance related to labor hours, flight

hours, availability and safety. The alternative maintenance case developed in Chapter V built upon the idea that the maximum benefit is attained by a re-engineering of the phase maintenance process. The alternative case was based on the elimination of inspections to IMDS monitored components and systems without an identified need. Current phase inspections of IMDS monitored components were determined to be needed only when a consistent exceedance of non-operable flight limits was identified. IMDS provides a robust ability to monitor and track trends in component and system performance, and this ability makes the alternative case feasible. This baseline was then compared to the alternative case to determine the differences in maintenance performance between the two models. In terms availability, flight hour usage and maintenance labor hour usage, the alternative case performed significantly better than the baseline case.

Using the data collected from operations over 13 months within the HSCWP, the value of the baseline and alternative cases were compared. Value was assessed based on a comparison of flight hours created per labor hour used to facilitate phase inspections. The result of this comparison was an average increase from 0.36 flight hours produced per labor hour under the baseline case to 1.073 flight hours produced under the alternative case. Additionally, implementation of the alternative case would result in a decrease in usage by 23,710 labor hours per year for the entire sample population. Flight hours available for operational tasking would increase by up to 3.24 percent, for a total of 382 flight hours across the entire sample population. On an average per-aircraft basis, each aircraft would attain an additional 5.7 flight hours for operational tasking per 175 flight hour phase cycle. The increase in flight hours is a direct result of the decrease in the need for post-phase vibration analysis and FCF due to changes in phase inspections.

Operational availability as a result of phase maintenance would increase from 0.69 to 0.937 on average for the entire sample population. In terms of availability, this change means that aircraft would be available for operational tasking on 93.7 percent of all days instead of 69 percent as a result of current phase inspections. Other factors affect the achieved operational availability, but the main cause of MH-60S unavailability is phase maintenance.

Finally, a review of the available flight safety data revealed that there was no greater risk to equipment by replacing inspection with IMDS monitoring. The flight safety data suggests that the majority of mechanical failures in the MH-60S were caused by human error in the maintenance process. Additionally, the relatively low number of mechanical failures in the MH-60S suggests that component quality does not require the level of inspection for which the NAMP phase maintenance process was designed.

A. STUDY EXTENSIONS

This study was conceived to determine the gap in capability to perform CBM at the operational maintenance level and the value attained by closing that gap. As the results show, this study succeeded in identifying that gap and proposing a solution to achieve value in the process. This study was limited to three helicopter squadrons that currently fly the MH-60S, all within the same administrative aviation wing on the West Coast. The HSCWP has 10 squadrons in its current configuration, so one logical extension would be to perform this study on all aircraft within the HSCWP. By expanding this study's methods to include all squadrons, a much more robust understanding of the value of CBM and IMDS could be attained. Due to the operational commitments of the squadrons in the HSCWP, this level of depth was impossible for this study using the most current data. Therefore, any extension of this study to include all of the HSCWP would require the storage of more than 12 months of maintenance data for all squadrons. Increasing the timeline would provide a more robust data set and longer-term histories of maintenance performance for individual aircraft and squadrons as a whole.

This study created a CBM alternative that was based on an evolution of the current NAMP phase process. As part of this study, the phase process was changed very little. Instead, the components of phase inspections were altered to reduce maintenance work-load and increase CBM. Furthermore, this study focused only on phase inspections and made no effort to alter the myriad of other conditional and special inspections required by the NAMP. A reasonable extension of this study would be to apply the same methods that were applied to phase inspections to special and conditional inspections.

Increasing the scope of this study would provide others areas within the NAMP where value could be attained by increasing CBM.

The final logical extension of this study would include a comparison of the NAMP process to the other service's maintenance processes. The H-60 provides an ideal platform for this extension, as the aircraft is flown by the Army, Navy, Air Force and Coast Guard. Comparison of these various processes would provide a robust series of alternatives to consider the efficacy of CBM. Moreover, the study of multiple current alternatives could provide the ability to create a hybrid process which utilizes the best practices of extant processes in conjunction with CBM. Through the large number of alternatives available in this comparison, a much better process could be developed.

B. RECOMMENDATIONS

As a result of the findings of this study, there are two primary recommendations that would improve the efficiency of Naval Aviation maintenance. These changes include the installation of IMDS on all MH-60S aircraft and a conversion to a CBM process to replace many current NAMP processes. The first recommendation is to increase the usage of IMDS in all MH-60S aircraft. Currently, the IMDS is not installed in all MH-60S, as is evidenced by the aircraft sample used in this study. It is clear that value does exist by converting to a CBM process, and that the Navy desires to attain this value. The IMDS is currently the only system in service that is capable of facilitating CBM in the MH-60S. Therefore, a great amount of value could be achieved by increasing the prevalence of IMDS in the MH-60S.

The second recommendation is to increase the use of CBM in place of the current NAMP maintenance processes. The value that is provided by IMDS, as this study clearly shows, can only be achieved by a conversion to a CBM process. CBM provides the ability to greatly minimize maintenance effort based on aircraft need. The current NAMP process has served the Navy well, but was definitively not designed with modern aircraft systems in mind. The use of inspections as the basis for maintaining aircraft has provided an excellent maintenance capability. On the other hand, modern systems which can constantly monitor performance provide a much more robust and accurate measure of

component performance than a periodic human inspection. Since these inspections are based on human measurement, the inspections are subject to human error. As the safety record indicates, if an aircraft system or component experiences a mechanical failure, it is most likely due to human error in the maintenance process.

The major question left unresolved by this study is what a CBM process would actually entail. The alternative CBM proposed by this study simply alters the current phase process to make more use of IMDS tools. In many ways, this alternative process is just a step in the evolution of CBM within the Navy. It is important to take that first step, but the alternative proposed in this study should not be taken as a final solution to CBM implementation. Much like the NAMP recognizes, process improvement is constant, and CBM will greatly evolve once the first steps in the direction of CBM are taken.

There is a vast improvement in system monitoring and diagnostic capability provided by IMDS over human inspections. Human inspection still does provide a great capability to augment automatic monitoring and would continue to do so under a CBM process. The accumulation of evidence, however, definitively shows that systematic monitoring and diagnostics, such as that provided by IMDS, greatly improves both performance and safety. A failure to recognize this fact or a reluctance to alter processes that are “good enough” will continue to cause waste and stress the limited resources of the DOD.

Installing IMDS on all MH-60S aircraft and converting to CBM will not come without costs. There will be a dollar cost associated with the installation and maintenance of the IMDS system. These monetary costs do seem as if they would be more than offset by the savings provided by a CBM process, but most cost related to IMDS would be incurred as part of the installation process.

Other costs associated with the change in culture at the operational level will be less monetary. Since the NAMP has been in place for over 50 years, all current Navy maintenance personnel are familiar and comfortable with the process. This trust in the NAMP processes will be difficult to overcome and will require great effort. Any new maintenance process must be allowed to experience the set-backs that will undoubtedly

occur. This emotional and economic investment is inevitable to increase the benefits of altering the maintenance process for future generation of aircraft. The current way of doing business in naval aviation has in many ways reached the breaking point, and the current fiscal reality does not support the continued use of expensive, outdated practices. The conversion of the MH-60S to CBM will allow maintenance departments to gain comfort in a new model on a familiar airframe. This comfort level will make the transition much smoother for future generations and greatly improve the war fighting capability of the U.S. Navy.

APPENDIX A. MAINTENANCE DATA.

Appendix A contains data related to maintenance labor hours, flight hours and availability. Labor hour data was attained from the OOMA records of each squadron, and flight hour data from SHARP databases. Flight Safety data is privileged and therefore not published except as anonymous statistical data in this study.

HSC-3

Aircraft	BUNO	IMDS	FCF Complete	Phase Start	Phase End	TBM	Phase Type	Phase Labor Hours	Phase FCF Hours	Days Unavailable	Special Type	Special Date
01	165756	N			5/16/2013		C				364	5/11/2014
			10/10/2013	7/16/2013	9/20/2013	39	D	1200.7	6.8	86	546	9/19/2013
			2/13/2014	1/25/2014	2/7/2014	107	A	424.8	1.5	19	728	4/25/2014
			5/30/2014	5/2/2014	5/14/2014	78	B	283.1	9.6	28		
			396					1908.6	17.9	133		
07	166323	Y			5/11/2012		B				364	3/19/2014
					8/10/2012		C				546	3/5/2014
					12/11/2012		D				728	9/13/2012
			7/18/2014	6/20/2014	6/30/2014	N/A	A	261.1	4.3	28		
08	166313	Y			6/13/2013		A				364	2/8/2014
			10/23/2013	8/28/2013	9/23/2013	44	B	197.7	6.6	56	546	2/5/2014
			2/12/2014	1/22/2014	2/5/2014	91	C	618.9	3.9	21	728	3/10/2013
			5/29/2014	4/23/2014	5/19/2014	70	D	890.1	3.5	36		
			396					1706.7	14	113		
09	166317	Y	10/30/2013	10/1/2013	10/11/2013	57	A	509.9	2.3	29	364	1/9/2014
			1/28/2014	1/17/2014	1/24/2014	79	B	230.8	3	11	546	6/1/2014
			4/2/2014	3/10/2014	3/20/2014	41	C	419.6	7.7	23	728	3/13/2014
			6/14/2014	5/10/2014	6/2/2014	38	D	455.1	4.8	35		
			256					1615.4	17.8	98		
11	166344	Y			12/9/2011		B				364	7/10/2013
					5/2/2012		C				546	5/13/2013
			5/10/2014	8/8/2013	4/2/2014	36	D	807.7	9	272	728	7/6/2013
			7/29/2014	7/1/2014	7/10/2014	52	A	194.2	4.6	28		
			396					1001.9	13.6	300		
12	166335	Y	9/5/2013	6/20/2013	8/13/2013	78	A	647.4	5.3	77	364	6/25/2014
			12/4/2013	11/14/2013	11/25/2013	70	B	285.1	2.3	20	546	6/19/2014
Key			3/11/2014	2/21/2014	3/4/2014	79	C	445	5.6	18	728	11/20/2013
Non-IMDS	No Data	IMDS	7/22/2014	4/8/2014	6/21/2014	28	D	1669.6	5.8	105		
Other Inspection			365					3047.1	19	220		

Aircraft	BUNO	IMDS	FCF Complete	Phase Start	Phase End	TBM	Phase Type	Phase Labor Hours	Phase FCF Hours	Days Unavailable	Special Type	Special Date
14	166350	N			9/13/2012		B				364	6/2/2014
					3/5/2013		C				546	5/8/2014
					6/14/2013		D				728	12/1/2012
			6/16/2014	8/5/2013	5/29/2014	35	A	461.9	7.5	311		
15	166365	N			4/30/2013		B				364	12/17/2013
			8/20/2013	7/13/2013	7/31/2013	65	C	545.7	7	38	546	4/26/2013
			1/9/2014	10/26/2013	11/22/2013	67	D	775.6	11.1	75	728	10/20/2013
			PMI	2/15/2014	2/26/2014	37	A	394.2	N/A	N/A		
			217					1715.5	18.1	113		
16	166343	N			2/8/2012		B				364	10/18/2013
					6/11/2012		C				546	4/16/2014
					10/16/2012		D				728	8/13/2013
			5/9/2014	4/1/2014	4/17/2014	N/A	A	653.6	6.1	38		
17	166369	N	11/18/2013	10/18/2013	11/13/2013	58	D	667.6	2.9	31	364	2/11/2014
			2/6/2014	1/24/2014	2/3/2014	67	A	368.3	6.3	13	546	7/30/2013
			5/9/2014	4/4/2014	4/29/2014	57	B	397	6.1	35	728	1/29/2014
			7/28/2014	6/28/2014	7/9/2014	50	C	222.5	7.7	30		
			286					1655.4	23	109		
20	165754	N			6/3/2011		B				364	3/21/2014
					11/10/2011		C				546	3/6/2014
			4/15/2014	3/12/2014	3/26/2014	PMI	D	981.1	7.5	33	728	4/26/2014
			7/10/2014	6/12/2014	6/23/2014	58	A	443.9	1.5	28		
			142					1425	9	61		
23	166306	N	10/25/2013	9/28/2013	10/16/2013	57	A	276.1	10.7	27	364	8/11/2013
			2/1/2014	12/12/2013	1/2/2014	48	B	577.9	10.2	51	546	1/23/2014
			4/22/2014	3/18/2014	3/28/2014	45	C	246.2	8.8	35	728	8/10/2012
			6/30/2014	5/31/2014	6/16/2014	39	D	564.7	5.9	30		
			275					1664.9	35.6	143		
24	166370	N	11/23/2013	9/26/2013	10/31/2013	48	D	1343.5	3.2	58	364	5/21/2014
			3/5/2014	1/30/2014	2/12/2014	68	A	383	4.7	34	546	10/30/2013
			5/14/2014	4/14/2014	5/5/2014	40	B	405	4.5	30	728	2/7/2014
			8/4/2014	7/12/2014	7/17/2014	59	C	232.7	4.1	23		
			312					2364.2	16.5	145		
28	165747	N			9/6/2012		A				364	1/29/2014
					3/12/2013		B				546	1/7/2014
			2/24/2014	8/1/2013	1/9/2014	83	C	515.4	7.2	207	728	11/14/2012
			7/8/2014	5/21/2014	6/10/2014	86	D	666.7	7.2	48		
			396					1182.1	14.4	255		
30	166293	N			1/23/2013		D				364	6/3/2014
			9/18/2013	8/25/2013	9/16/2013	199	A	431.8	3	24	546	9/16/2013
			1/18/2014	12/6/2013	12/13/2013	79	B	523.2	12.6	43	728	3/31/2014
Key			1/18/2014	12/6/2013	12/13/2013	79	B	523.2	12.6	43	728	3/31/2014
Non-IMDS No Data		IMDS	5/9/2014	4/4/2014	4/23/2014	78	C	380.3	2.5	35		
Other Inspection			396					1335.3	18.1	102		

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Aircraft	BUNO	IMDS?	FCF Complete	Phase Start	Phase Complete	Phase Type	TBM	Phase Labor Hours	Phase FCF Hours	Days Unavailable
610	167869	Y			9/21/2012	A				
					1/20/2013	B				
			10/10/2013	8/29/2013	9/25/2013	C	220	296.9	8.2	42
			3/20/2014	2/21/2014	3/18/2014	D	134	647.4	2.6	27
			396					944.3	10.8	69
611	168394	Y			2/25/2013	C				
			8/6/2013	7/9/2013	8/1/2013	D	132	576.8	3.8	28
			11/7/2013	10/17/2013	10/31/2013	A	72	178.9	3.7	21
			4/3/2014	3/13/2014	3/25/2014	B	126	207.8	1.5	21
			396					963.5	9	70
612	166311	N			12/16/2011	D				
					6/20/2013	A				
			3/18/2014	11/20/2013	11/27/2013	B	148	132.5	5.2	118
			7/18/2014	6/25/2014	7/7/2014	C	99	173.3	12.3	23
			396					305.8	17.5	141
613	168395	Y			3/8/2013	C				
			9/10/2013	8/6/2013	9/3/2013	D	142	683.1	4.8	35
			1/28/2014	1/14/2014	1/27/2014	A	126	152.1	2.2	14
			6/2/2014	5/15/2014	5/29/2014	B	107	302	2.2	18
			396					1137.2	9.2	67
614	167875	Y			1/6/2013	C				
					5/23/2013	D				
			11/22/2013	11/12/2013	11/20/2013	A	120	184.8	2.4	10
			4/16/2014	3/27/2014	4/11/2014	B	125	142.5	3	20
			396					327.3	5.4	30
615	166357	Y			7/25/2011	C				
					3/24/2012	D				
			8/1/2013	7/1/2013	7/30/2013	A	242	1402.7	3.8	31
			10/29/2013	10/9/2013	10/23/2013	B	69	445.2	3.8	20
			396					1847.9	7.6	51
616	167859	Y			1/23/2013	B				
					3/22/2013	C				
			3/3/2014	9/10/2013	2/18/2014	D	157	504.6	9.4	174
			6/12/2014	5/28/2014	6/8/2014	A	86	145.9	2.6	14
			396					650.5	12	188
617	167867	Y			2/13/2013	D				
					6/13/2013	A				
			1/7/2014	11/19/2013	12/19/2013	B	152	462.2	3.5	49
			5/1/2014	4/10/2014	4/22/2014	C	93	230.7	5.3	21
			396					692.9	8.8	70
620	166307	N			11/22/2011	A				
					2/28/2012	B				
			10/2/2013	8/6/2013	9/18/2013	C	90	156.1	4.8	57
Key										
Non-IMDS No Data		IMDS	6/17/2014	11/19/2013	5/12/2014	D	48	454.8	13.1	210
Other Inspection			396					610.9	17.9	267

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Aircraft	BUNO	IMDS	FCF Complete	Phase Start	Phase Complete	Phase Type	TBM	Phase Labor Hours	Phase FCF Hours	Days Unavailable	Special Type	Special Date
76	166332	N			3/27/2013	B					364	12/19/2013
			7/8/2013	6/10/2013	6/24/2013	C	67	398.6	3.9	28	546	11/1/2012
			10/7/2013	9/8/2013	9/24/2013	D	62	410.9	9.3	29	728	10/30/2012
			1/24/2014	12/15/2013	12/20/2013	A	69	373.4	14.3	41		
			396					1182.9	27.5	98		
62	166348	N			1/10/2012	A					364	5/27/2014
					5/9/2012	B					546	5/28/2014
					12/26/2012	C					728	12/11/2012
			7/25/2013	6/11/2013	7/15/2013	D	134	1305.8	9.8	44		
			396					1305.8	9.8	44		
71	166362	N	10/7/2013	9/30/2013	10/5/2013	A	84	220.4	5.1	7	364	11/15/2013
			11/25/2013	11/11/2013	11/17/2013	B	35	297.8	6.5	14	546	6/6/2013
			3/1/2014	2/21/2014	2/28/2014	C	88	132.2	2.9	8	728	8/29/2013
			7/10/2014	6/16/2014	7/2/2014	D	107	957.5	4.6	24		
			283					1607.9	19.1	53		
70/75	166315	N			2/26/2013	A					364	7/9/2014
			2/20/2014	1/29/2014	2/11/2014	B	117	543.9	4.3	22	546	2/13/2014
			5/15/2014	5/6/2014	5/13/2014	C	75	159.1	5.3	9	728	2/19/2014
			7/31/2014	7/10/2014	7/23/2014	D	56	162	4.8	21		
			396					865	14.4	52		
74	166319	N			12/20/2011	C					364	1/31/2014
					4/17/2013	D					546	12/3/2013
			12/13/2013	10/31/2013	11/26/2013	A	78	720.3	4	44	728	10/29/2012
Key												
Non-IMDS	No Data	IMDS	PMI	4/7/2014	4/13/2014	B	115	553.8	N/A	N/A		
Other Inspection			396					1274.1	4	44		

ALL SQUADRONS

Aircraft	BUNO	IMDS	Scheduled Hours	Unscheduled Hours	Total Labor Hours	Total FCF Hours	Total Flight Hours	FCF/Flight Hours	Schedule Labor %
62	166348	N	1594.2	2823.3	4417.5	16.8	65.9	25.49%	36.09%
616	167859	Y	1708.9	1926.1	3635	16	261.1	6.13%	47.01%
20	165754	N	3896.2	3531.4	7427.6	10.3	247.4	4.16%	52.46%
14	166350	N	2328.2	2093.5	4421.7	14.4	319.3	4.51%	52.65%
612	166311	N	4078.9	3613.7	7692.6	19.5	141	13.83%	53.02%
617	167867	Y	2475.6	2063.7	4539.3	11.8	347.7	3.39%	54.54%
16	166343	N	4848.3	3965	8813.3	21.8	343.2	6.35%	55.01%
70/75	166315	N	5794.8	4310	10104.8	20.2	507.1	3.98%	57.35%
74	166319	N	4574.9	3337	7911.9	11.4	303.1	3.76%	57.82%
08	166313	Y	5458.6	3336.5	8795.1	32.1	606.8	5.29%	62.06%
620	166307	N	3557.1	2105.1	5662.2	13.1	62.8	20.86%	62.82%
11	166344	Y	3310	1924.1	5234.1	15.3	282	5.43%	63.24%
76	166332	N	3592.8	2060.7	5653.5	28.5	331.3	8.60%	63.55%
28	165747	N	4606.7	2526	7132.7	17.4	281.9	6.17%	64.59%
615	166357	Y	4346.6	2338.7	6685.3	3.1	14.3	21.68%	65.02%
614	167875	Y	2855.9	1505.9	4361.8	15.9	472	3.37%	65.48%
23	166306	N	6017.8	2853.2	8871	49.9	748.7	6.66%	67.84%
30	166293	N	5071.4	2386.4	7457.8	23.2	499.4	4.65%	68.00%
09	166317	Y	6515.9	3020.4	9536.3	39.9	868	4.60%	68.33%
12	166335	Y	6710.4	3094.4	9804.8	26	509.1	5.11%	68.44%
613	168395	Y	3674	1637.2	5311.2	16	492.9	3.25%	69.17%
17	166369	N	6549.2	2788.9	9338.1	29.4	751.1	3.91%	70.13%
71	166362	N	6728	2738.6	9466.6	53.9	752.8	7.16%	71.07%
24	166370	N	6778	2731.8	9509.8	26.9	693.5	3.88%	71.27%
15	166365	N	3828	1509.9	5337.9	28.9	366.5	7.89%	71.71%
611	168394	Y	3439.4	1293.5	4732.9	10.5	494.2	2.12%	72.67%
610	167869	Y	2684.7	959.9	3644.6	11.8	298.4	3.95%	73.66%
01	165756	N	5239.9	1803.9	7043.8	26.2	506.4	5.17%	74.39%
07	166323	Y	5401.1	607.5	6008.6	12.7	207.8	6.11%	89.89%
Key		Total	127665.5	70886.3	198551.8	622.9	11775.7	5.29%	64.30%
non-IMDS	IMDS	Average	4402.3	2444.4	6846.6	21.5	406.1	5.29%	64.30%

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APPENDIX B. IMDS DATA

Appendix B contains all IMDS Ground Station Data recorded from HSC-3 and HSC-8. Main Rotor balance data was collected from the ground station in each squadron and tail rotor, input shaft, and disconnect coupling data were collected from IMDS MDAT databases. BUNOs 166323, 166313, 166317, 166344, and 166335 were part of the HSC-3 inventory and BUNOs 167869, 168394, 168395, 167875, 166357, 167859, and 167867 were part of the HSC-8 inventory. All exceedances of non-operable flight limits appear in red, and trends requiring additional inspection also appear in red.

HSC-3

BUNO/System	RPM	Phase	Start Date	End Date	High Value	Mean	STD DEV	Limit	Trend / Consistent Exceedance
166323									
Main Rotor 1/per vert	258	A		6/20/2014	0.207	0.101		0.35	None
Main Rotor 1/per roll	258				0.284	0.209		0.3	None
Tail Rotor 1/per	1189				1.026	0.1091	0.1128	0.55	No, Several Spikes above .45 on 4/24 and 4/28
STBD ENG Input Shaft	20900				0.2	0.0728	0.0272	1	None
PORT ENG Input Shaft	20900				0.636	0.2475	0.1477	1	No, Spike from .2 to .5 range after 6/20
Disconnect Coupling	4114				0.17	0.0811	0.0315	0.86	None
166313									
Main Rotor 1/per vert	258	A	6/13/2013	8/28/2013				0.35	N/A
Main Rotor 1/per roll	258							0.3	N/A
Tail Rotor 1/per	1189				0.449	0.1302	0.0507	0.55	No, Spike from .1 to .4 range on 8/20
STBD ENG Input Shaft	20900				0.0893	0.0454	0.01	1	No Trend
PORT ENG Input Shaft	20900				0.252	0.1206	0.0291	1	No Trend
Disconnect Coupling	4114				0.197	0.0699	0.0355	0.86	No Trend
Main Rotor 1/per vert	258	B	10/23/2013	1/22/2014	0.111	0.038		0.35	None, Data not available for entire period
Main Rotor 1/per roll	258				0.225	0.133		0.3	None, Data not available for entire period
Tail Rotor 1/per	1189				0.534	0.0969	0.0574	0.55	Spikes to .5 on 10/29 and .4 on 11/18
STBD ENG Input Shaft	20900				0.192	0.0765	0.0364	1	None
PORT ENG Input Shaft	20900				0.304	0.1502	0.0553	1	None, 0.12 trend up to 0.24 on 1/1/14
Disconnect Coupling	4114				0.19	0.0751	0.0351	0.86	None, Stable at .04 or .10
Main Rotor 1/per vert	258	C	2/12/2014	4/23/2014	0.241	0.074		0.35	None
Main Rotor 1/per roll	258				0.139	0.026		0.3	None
Tail Rotor 1/per	1189				0.165	0.081	0.0235	0.55	None
STBD ENG Input Shaft	20900				0.212	0.0661	0.0529	1	None
PORT ENG Input Shaft	20900				0.376	0.2212	0.0427	1	None
Disconnect Coupling	4114				0.174	0.0813	0.0284	0.86	None
Main Rotor 1/per vert	258	D	5/29/2014		0.231	0.168		0.35	None
Main Rotor 1/per roll	258				0.154	0.074		0.3	None
Tail Rotor 1/per	1189				0.27	0.1271	0.0249	0.55	None
STBD ENG Input Shaft	20900				0.914	0.0901	0.0784	1	No, Spike to .7 on 7/29
PORT ENG Input Shaft	20900				1.961	0.0322	0.0155	1	No, Spike to 1.4 on 7/29
Disconnect Coupling	4114				0.197	0.0758	0.0325	0.86	None

BUNO/System	RPM	Phase	Start Date	End Date	High Value	Mean	STD DEV	Limit	Trend / Consistent Exceedance
166317									
Main Rotor 1/per vert	258	A		10/1/2013				0.35	N/A
Main Rotor 1/per roll	258							0.3	N/A
Tail Rotor 1/per	1189				0.779	0.1944	0.0897	0.55	No, Spike on 9/18 to 0.7
STBD ENG Input Shaft	20900				0.963	0.1025	0.1237	1	None after adjustment
PORT ENG Input Shaft	20900				0.0695	0.0246	0.0128	1	None
Disconnect Coupling	4114				0.822	0.3505	0.1599	0.86	No, Clear Trend up, 0.2 to 0.7 then down to 0.4
Main Rotor 1/per vert	258	B	10/30/2013	1/17/2014	0.183	0.163		0.35	None, Data not available for entire period
Main Rotor 1/per roll	258				0.159	0.076		0.3	None, Data not available for entire period
Tail Rotor 1/per	1189				1.086	0.1316	0.089	0.55	No, Spikes on 11/1 and 12/18
STBD ENG Input Shaft	20900				0.32	0.1053	0.0538	1	None
PORT ENG Input Shaft	20900				0.633	0.4203	0.0814	1	None
Disconnect Coupling	4114				1.03	0.5301	0.1433	0.86	No, Consistently in 0.5-0.7 Range
Main Rotor 1/per vert	258	C	1/28/2014	3/10/2014	0.272	0.168		0.35	N
Main Rotor 1/per roll	258				0.166	0.065		0.3	N
Tail Rotor 1/per	1189				0.371	0.1088	0.0761	0.55	No, Trend Up from 0.05 to 0.25
STBD ENG Input Shaft	20900				0.322	0.0966	0.0566	1	None
PORT ENG Input Shaft	20900				0.429	0.1254	0.0945	1	No, Trend 0.3 drops to 0.06 on 2/10
Disconnect Coupling	4114				1.027	0.4398	0.167	0.86	No, High Early Trend 0.7 decreasing to 0.3
Main Rotor 1/per vert	258	D	4/2/2014	5/10/2014	0.183	0.094		0.35	None
Main Rotor 1/per roll	258				0.157	0.041		0.3	None
Tail Rotor 1/per	1189				0.517	0.2914	0.1427	0.55	No, Jump from 0.05 to 0.4 on 4/14 onward
STBD ENG Input Shaft	20900				0.809	0.5115	0.0798	1	None
PORT ENG Input Shaft	20900				0.22	0.0904	0.0199	1	None
Disconnect Coupling	4114				0.656	0.4612	0.0737	0.86	None
166344									
Main Rotor 1/per vert	258	D		3/19/2014				0.35	N/A
Main Rotor 1/per roll	258							0.3	N/A
Tail Rotor 1/per	1189				1.018	0.351	0.2323	0.55	Yes, Steady Climb from .15 to 1.0
STBD ENG Input Shaft	20900				0.8	0.2383	0.0676	1	None
PORT ENG Input Shaft	20900				2.072	0.1392	0.2093	1	No, Spike associated with FCF on first runs
Disconnect Coupling	4114				0.308	0.1361	0.0599	0.86	None
Main Rotor 1/per vert	258	A	5/10/2014	7/1/2014	0.28	0.09		0.35	None
Main Rotor 1/per roll	258				0.17	0.088		0.3	None
Tail Rotor 1/per	1189				0.5	0.2779	0.0792	0.55	None, Spike on 4/24-4/27 to 0.45
STBD ENG Input Shaft	20900				0.16	0.0842	0.0211	1	None
PORT ENG Input Shaft	20900				0.23	0.1368	0.0249	1	None
Disconnect Coupling	4114				0.341	0.1318	0.0578	0.86	None

BUNO/System	RPM	Phase	Start Date	End Date	High Value	Mean	STD DEV	Limit	Trend / Consistent Exceedance
166335									
Main Rotor 1/per vert	258	A		7/22/2013				0.35	N/A
Main Rotor 1/per roll	258							0.3	N/A
Tail Rotor 1/per	1189				0.442	0.285	0.0378	0.55	None
STBD ENG Input Shaft	20900				0.418	0.3427	0.0835	1	None
PORT ENG Input Shaft	20900				1.851	0.1919	0.1396	1	None, Spike to 1.8 on 4/7 then back to 0.2
Disconnect Coupling	4114				0.352	0.1811	0.0622	0.86	None
Main Rotor 1/per vert	258	B	9/5/2013	11/14/2013				0.35	N/A
Main Rotor 1/per roll	258							0.3	N/A
Tail Rotor 1/per	1189				0.415	0.2706	0.0381	0.55	None
STBD ENG Input Shaft	20900				0.594	0.3115	0.0471	1	None
PORT ENG Input Shaft	20900				0.338	0.1851	0.0705	1	None
Disconnect Coupling	4114				0.297	0.1736	0.048	0.86	None, Declining through period
Main Rotor 1/per vert	258	C	12/4/2013	2/21/2014	0.287	0.203		0.35	None
Main Rotor 1/per roll	258				0.292	0.183		0.3	None
Tail Rotor 1/per	1189				0.269	0.0897	0.0436	0.55	No, Jump from .1 to .15 on 2/14
STBD ENG Input Shaft	20900				0.547	0.2726	0.0513	1	None
PORT ENG Input Shaft	20900				0.338	0.166	0.0635	1	None
Disconnect Coupling	4114				0.348	0.1865	0.058	0.86	None
Main Rotor 1/per vert	258	D	3/11/2014	4/8/2014	0.278	0.055		0.35	None
Main Rotor 1/per roll	258				0.159	0.041		0.3	None
Tail Rotor 1/per	1189				0.193	0.0907	0.0335	0.55	None
STBD ENG Input Shaft	20900				0.572	0.2743	0.0514	1	None
PORT ENG Input Shaft	20900				0.355	0.1739	0.0661	1	None
Disconnect Coupling	4114				0.352	0.1865	0.0872	0.86	None

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Aircraft System	RPM	Phase	Start Date	End Date	High Value	Mean	STD DEV	Limit	Trend / Consistent Exceedance
167869									
Main Rotor 1/per vert	258	C	1/20/2013	8/29/2013	0.303	0.179		0.35	None
Main Rotor 1/per roll	258				0.192	0.106		0.3	None
Tail Rotor 1/per	1189				0.433	0.3499	0.0444	0.55	None
STBD ENG Input Shaft	20900				0.899	0.7507	0.0721	1	No, Trend up from .64 to .82
PORT ENG Input Shaft	20900				0.26	0.1501	0.0413	1	None
Disconnect Coupling	4114				0.148	0.0746	0.0308	0.86	None
Main Rotor 1/per vert	258	D	10/10/2013	2/21/2014	0.329	0.19		0.35	None
Main Rotor 1/per roll	258				0.224	0.097		0.3	None
Tail Rotor 1/per	1189				0.372	0.1563	0.0478	0.55	No, Spike to .28 between 2-7/2-10-14
STBD ENG Input Shaft	20900				0.567	0.354	0.0807	1	No, Trend up .3 to .5
PORT ENG Input Shaft	20900				0.361	0.2049	0.0403	1	None
Disconnect Coupling	4114				0.184	0.0884	0.0297	0.86	None, trend up to .125 after 2-10-14
168394									
Main Rotor 1/per vert	258	D	2/25/2013	7/9/2013	0.13	0.09		0.35	None
Main Rotor 1/per roll	258				0.11	0.083		0.3	None
Tail Rotor 1/per	1189				0.47	0.2048	0.1291	0.55	None
STBD ENG Input Shaft	20900				0.46	0.2425	0.0441	1	None
PORT ENG Input Shaft	20900				0.54	0.338	0.0428	1	None
Disconnect Coupling	4114				0.22	0.0887	0.0476	0.86	None
Main Rotor 1/per vert	258	A	8/6/2013	10/17/2013	0.238	0.092		0.35	None
Main Rotor 1/per roll	258				0.178	0.053		0.3	No, 1 HVR exceedance
Tail Rotor 1/per	1189				0.078	0.013	0.0085	0.55	None
STBD ENG Input Shaft	20900				0.351	0.1981	0.0378	1	None
PORT ENG Input Shaft	20900				0.528	0.288	0.0576	1	None
Disconnect Coupling	4114				0.192	0.0814	0.0368	0.86	None
Main Rotor 1/per vert	258	B	11/7/2013	3/13/2014	0.161	0.142		0.35	None
Main Rotor 1/per roll	258				0.054	0.052		0.3	None
Tail Rotor 1/per	1189				0.471	0.0744	0.0654	0.45	No, Spike to .2 and .3 from 11-20/11-26
STBD ENG Input Shaft	20900				0.44	0.2233	0.0572	1	No Trend
ENG Output Shaft	20900				0.508	0.3054	0.0696	1	No Trend
Disconnect Coupling	4114				0.217	0.0718	0.0453	0.4	No Trend
168395									
Main Rotor 1/per vert	258	D	3/8/2013	8/6/2013				0.35	N/A
Main Rotor 1/per roll	258							0.3	N/A
Tail Rotor 1/per	1189				0.181	0.0812	0.0351	0.45	None
STBD ENG Input Shaft	20900				0.242	0.1033	0.0315	1	None
PORT ENG Input Shaft	20900				0.54	0.3854	0.0526	1	None
Disconnect Coupling	4114				0.101	0.0409	0.0203	0.4	None
Main Rotor 1/per vert	258	A	9/10/2013	1/14/2014	0.257	0.049		0.35	None
Main Rotor 1/per roll	258				0.273	0.173		0.3	None
Tail Rotor 1/per	1189				0.176	0.052	0.0336	0.55	None
STBD ENG Input Shaft	20900				0.289	0.0936	0.0323	1	None
PORT ENG Input Shaft	20900				2.847	0.3696	0.1792	1	Yes: Spike to 2.8 on 9-25/9-29
Disconnect Coupling	4114				0.116	0.0385	0.0212	0.86	None
Main Rotor 1/per vert	258	B	1/28/2014	5/15/2014	0.19	0.072		0.35	None
Main Rotor 1/per roll	258				0.247	0.183		0.3	None
Tail Rotor 1/per	1189				0.731	0.2537	0.1739	0.55	Yes: Large Data Range, many over .45 from 4-2/4-6
STBD ENG Input Shaft	20900				0.251	0.0988	0.0331	1	None
PORT ENG Input Shaft	20900				0.519	0.3872	0.0537	1	None
Disconnect Coupling	4114				0.0996	0.0329	0.0176	0.86	None

Aircraft System	RPM	Phase	Start Date	End Date	High Value	Mean	STD DEV	Limit	Trend / Consistent Exceedance
167875									
Main Rotor 1/per vert	258	A	5/23/2013	11/12/2013	0.437	0.177		0.35	None
Main Rotor 1/per roll	258				0.23	0.1		0.3	None
Tail Rotor 1/per	1189				0.248	0.1656	0.0424	0.55	No, Slow Climb from .12 to .2
STBD ENG Input Shaft	20900				0.0598	0.0153	0.0075	1	None
PORT ENG Input Shaft	20900				0.534	0.3219	0.0492	1	None
Disconnect Coupling	4114				0.302	0.1018	0.0563	0.86	No, Some Higher Peaks, Flucuating Trend
Main Rotor 1/per vert	258	B	11/22/2013	3/27/2014	0.762	0.222		0.35	Yes: 3/18-3/26 (4 Flights)
Main Rotor 1/per roll	258				0.499	0.145		0.3	Yes: 3/18-3/26 (4 Flights)
Tail Rotor 1/per	1189				0.197	0.0748	0.0253	0.55	No, Trend Down from .15 to .08
STBD ENG Input Shaft	20900				0.251	0.1206	0.0497	1	None
PORT ENG Input Shaft	20900				0.439	0.3531	0.04	1	None
Disconnect Coupling	4114				0.208	0.0942	0.0448	0.86	None
166357									
Main Rotor 1/per vert	258	A	3/24/2012	7/1/2013				0.35	N/A
Main Rotor 1/per roll	258							0.3	N/A
Tail Rotor 1/per	1189							0.55	N/A
	20900							1	N/A
ENG Output Shaft	20900							1	N/A
Disconnect Coupling	4114							0.86	N/A
Main Rotor 1/per vert	258	B	8/1/2013	10/9/2013	0.1	0.039		0.35	None
Main Rotor 1/per roll	258				0.172	0.154		0.3	None
Tail Rotor 1/per	1189							0.55	N/A
STBD ENG Input Shaft	20900							1	N/A
PORT ENG Input Shaft	20900							1	N/A
Disconnect Coupling	4114							0.86	N/A

Aircraft System	RPM	Phase	Start Date	End Date	High Value	Mean	STD DEV	Limit	Trend / Consistent Exceedance
167859									
Main Rotor 1/per vert	258	D	3/22/2013	9/10/2013	0.293	0.168		0.35	None
Main Rotor 1/per roll	258				0.251	0.128		0.3	None
Tail Rotor 1/per	1189				0.869	0.6653	0.0956	0.55	Yes, Trend High, Adjusted Down to 0.5 Range on 9/6
STBD ENG Input Shaft	20900				0.516	0.3437	0.0508	1	None
PORT ENG Input Shaft	20900				0.521	0.28	0.0953	1	None
Disconnect Coupling	4114				0.294	0.106	0.0636	0.86	No, Down from 0.2
Main Rotor 1/per vert	258	A	3/3/2014	5/28/2014	0.271	0.159		0.35	None
Main Rotor 1/per roll	258				0.205	0.052		0.3	None
Tail Rotor 1/per	1189				0.205	0.0871	0.0271	0.55	None
STBD ENG Input Shaft	20900				0.889	0.478	0.0703	1	None
PORT ENG Input Shaft	20900				0.47	0.1473	0.035	1	None
Disconnect Coupling	4114				0.251	0.0723	0.0393	0.86	None
167867									
Main Rotor 1/per vert	258	B	6/13/2013	11/19/2013	0.372	0.106		0.35	None, 2x single exceedance in July and September
Main Rotor 1/per roll	258				0.24	0.107		0.3	None
Tail Rotor 1/per	1189				0.368	0.1484	0.0633	0.55	None
STBD ENG Input Shaft	20900				0.555	0.2988	0.1096	1	None
PORT ENG Input Shaft	20900				0.195	0.1065	0.0251	1	None
Disconnect Coupling	4114				0.18	0.094	0.045	0.86	None
Main Rotor 1/per vert	258	C	1/7/2014	4/10/2014	0.401	0.188		0.35	No, single exceedance
Main Rotor 1/per roll	258				0.238	0.041		0.3	None
Tail Rotor Vibes	1189				0.699	0.1327	0.0503	0.55	No, Single recording above 0.3
STBD ENG Input Shaft	20900				0.549	0.3192	0.1236	1	None
PORT ENG Input Shaft	20900				0.187	0.096	0.0295	1	None
Disconnect Coupling	4114				0.244	0.1002	0.0489	0.86	None

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